LIGO SURF Project Plan
Noise hunting in Advanced LIGO

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By: Michael Antia
Mentor: Dr. Jessica McIver

Introduction/Background

On September 14, 2015, for the first time in history, the Advanced LIGO detectors observed a gravitational wave signal (GW150914), with a significance greater than 5.1 σ [1]. 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" [2]. Due to the small amplitudes of gravitational waves, detecting them required 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 eliminating or isolating sources of noise, both environmental and instrumental. Commissioning efforts in characterizing noise and improving strain sensitivity will allow LIGO to further enhance its detection range from a present value of 60 – 80 Mpc for a BNS detection, to 80 – 120 Mpc for a run in 2016-2017, 120 – 170 Mpc for a run in 2017-2018, and to a full sensitivity of 200 Mpc range for a BNS detection by 2019 [3].

Several known noise sources include but are not limited to: anthropogenic noise, seismic activity, radio frequency modulation, blip transients, electromagnetic noise, quantum noise and thermal noise [1,3]. This project proposal will mainly focus on the characterization of seismic noise, more specifically on the effects of non-linear seismic coupling which manifests itself in jumps between frequency bands. One possible cause for the non-linear coupling can be attributed to the effect of wind causing infrastructure and instrumentation to tilt. Another possible explanation consists in the "Barkhausen effect in ferromagnetic components used for interferometer control signals" [4]. Understanding and addressing the mechanisms behind the seismic non-linear coupling will consequently improve data quality and minimize deadtime, thereby enhancing gravitational wave searches.

Objectives

The aim of this project is to identify correlations between the gravitational wave strain channel h(t), the interferometer cavity degrees-of-freedom, ground motion monitors and inertial sensors, and optical alignment actuation channels. The interferometer degrees of freedom consist of five components: Differential Arm (DARM), Common Arm (CARM), Michelson

Interferometer (MICH), Signal Recycling Cavity Length (SRCL), and Power Recycling Cavity Length (PRCL). These five components are defined as:* [5]

- **MICH** –the difference in length between the beam splitter (BS) and each of the input test mass optics (ITMX and ITMY).

- **DARM** –the difference between the two interferometer arm lengths. This mode is the basis for the measured gravitational wave signal.

- **CARM** –the average length of the two interferometer arms.

- **PRCL** –the sum of the distance between the beam splitter and the power recycling mirror and average of the lengths between the beam splitter and each input test mass optic.

- **SRCL** –the sum of the distance between the beam splitter and the signal recycling mirror and average of the lengths between the beam splitter and each input test mass optic.

Ground motion and inertial sensors complement a group of monitors named Physical Environment Monitors (PEMs). These sensors monitor the local environment and they are comprised of: seismometers and accelerometers which measure vibration of ground and interferometer components; microphones to measure acoustic noise; magnetometers that measure local electromagnetic fields; radio receivers; temperature sensors; and mains voltage monitors, to name a few [1]. The motion monitors that will be observed are Streckeisen STS2s, which measures ground motion from frequencies of 8 mHz to 20 Hz; and the Geotech GS-13 inertial sensors mounted on the auxiliary optics [6]. The auxiliary optics, which are housed in the Horizontal Access Module - Inertial Seismic Isolation chamber (HAM-ISI), consists of the Output Mode Cleaner (OMC); Signal Recycling Cavity (SRC); Input Mode Cleaner (IMC); and Power Recycling Cavity (PRC). The inertial sensors on the optical tables will be used to obtain data on the translational motion with reference to the natural X, Y and Z basis of the interferometer arms and rotational motion about the X, Y and Z axis. Other channels to be studied are the alignment channels – which are responsible for sensing and controlling the angular position of the mirrors.

The criteria for project completion is determined by accomplishing the following:

- Collect data from the gravitational wave strain channel h(t), the interferometer degrees-of-freedom, the motion sensors, and the optic control and alignment channels in order to compare, analyze and identify correlations between noise sources and h(t).

- Create a bin of all possible permutations of all degrees of freedom and channels analyzed, plot the data and create a series of videos for each channel permutation.

- Upon analyzing the results and identifying the correlations, the mechanism that causes the noise source to couple to h(t) will be investigated.

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* *Definitions are taken verbatim from referenced source with the exception of PRCL and SCRL*

Approach

The requirements for this project are: a laptop, Python, Bash, and Vim text editor. The approach to the project is the following:

- Weeks 1 – 2: the initial goal is to train on software and gain familiarity with the instruments. It will be required to know how to get data for a channel, how to read it, and how to collect certain aspects of data and manipulate them using Python. It will also be necessary to obtain a better understanding of the interferometer degrees of freedom.

- Weeks 3 – 7: the following step is to create a table of permutations and to write a code in order to make plots and videos with the permutation of all the channels. There will be occasions where I will be able to interact the with instrumental group, though project completion will not depend on results from other groups in related projects. The permutation of channels includes and are not limited to: measuring the angular motion of an optic in the SRC with pitch and yaw versus SRCL or DARM or CARM; measuring the ground motion and correlating it to the translational motion of an optic in the PRCL, SRCL, DARM, MICH or CARM degrees-of-freedom; measuring the angular and translational motion of the BS or (ITM) and comparing it the motion of the optics in the IMC or OMC.

- Weeks 8 – 10: the results will be analyzed, a final summary will be submitted and presented, and ideally the mechanism that couples to the gravitational wave strain channel is discovered.

References

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