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Scatter Coupling Studies at the LIGO Livingston Observatory

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Introduction/Background

The Laser Interferometric Gravitational-Wave Observatory (LIGO) is a set of gravitational wave detectors that seeks to use large ground-based interferometers to observe gravitational radiation from astrophysical sources. The two detector facilities are located in Hanford, WA (LHO, the LIGO Hanford Observatory) and Livingston, LA (LLO, the LIGO Livingston Observatory). Given the expected amplitudes of these gravitational waves, the expected length perturbations within the ~4km arms of either detector are on the order of one part in 10^{21} [1]. With this astronomically large amount of required precision, the need for noise reduction in the measurements of the LIGO detectors is paramount, and noise reduction has been the limiting factor in successful detection of gravitational waves in all of the past incarnations of LIGO. In 2010, the LIGO detectors began their transition to Advanced LIGO (aLIGO), which is expected to have drastically lowered noise thresholds at all frequencies of interest [3,4].

However, the current advanced LIGO apparatus still suffers from a variety of non-astrophysical noise sources, which can generally be separated into seismic, magnetic, acoustic, and Radio Frequency (RF) types. The types we will be focusing on during this ten week project are the seismic and acoustic noise sources. Specifically, we will be concerned with how light scattered from the main interferometer beam at LLO can be scattered off of any surface in the various optical cavities, be affected by their individual vibrations, and then recombine with the original beam. When this beam, which now modulated by a source vibrating within the range of interest of ~10-10000Hz that aLIGO is designed to measure, reaches the detector, it creates a gravitational wave(GW)-like signal [5] on the final photodiode, and thus creates signal-obscuring background noise.

This noise, caused by the combination of scattered light and vibrating components, is one of the leading sources of non-astrophysical noise for aLIGO. As such, the purpose of this project is to determine, using injection techniques [2], which specific parts of the LLO apparatus are the limiting contributors of noise, and which can be ignored. We will be concerned especially with the HAM6, BSC1, 3, 4, and 5 chambers of the LLO detector and the various potential scattering sources therein. These chambers are of interest because they contain the main beam as a source of the scattered light.

If we are successful in identifying the main sources of this seismic and acoustic scattering noise, we will be able to specifically target those sources with subsequent noise reduction techniques and/or devices. Since those working on the noise reduction efforts will be able to focus their efforts on very specific elements of the detector, their work will hopefully be quicker and more specialized and effective. This will lead to a significant reduction in the noise threshold for the

LLO detector, which will have obvious benefits for the accuracy and precision with which the detector can detect gravitational radiation.

Objectives/Approach

We will consider several specific elements of the LLO detector as possible light scatterers. First, we will consider the walls of the various chambers. Not only will it be useful to ascertain whether or not the inner walls of the chamber contribute significantly to scattering noise, it will also be important to understand whether the scattering effects can be localized to any specific part(s) of the chamber walls, or if the observed scattering noise is fairly constant throughout the detector. Both of these questions can be answered using injection techniques.

In order to determine whether a wall (or part of a wall) being examined is a source of scattering noise, we can use either a weighted shaker or a “burst injection” (e.g. “tapping”) of a predetermined frequency spectrum to excite vibrations in the wall. Then, we can compare the observed intensity data from the primary photodiode signal with both predetermined models for the expected scattering noise created from our injection [5], as well as previously taken “background” intensity data. We will use pre-existing scattering models [5] as well as various MatLab functions to create our scattering models and compare our models and measured data for coherence of the expected and measured signals.

If the observed noisy signal is found to be coherent with our predicted noisy signal and is of significant strength, then we can assume that whatever we excited may be a significant source of scattering noise, and we will mark that element for noise reduction. If we observe no new noise due to this specific injection, we can assume, given we are confident in our modeling, that the excited object or region is not a significant source of noise. If we do notice increased noise due to our injections, but it is not sufficiently coherent with our model, then we can assume that there is some other scattering source that is coupled to whatever we were exciting. This procedure should be repeated on many different locations along the outside walls of the chambers of interest, as previously mentioned, to try and determine if there are any “hot spots” of scattering along the chamber walls that should receive special attention when implementing further noise reduction measures.

This general strategy of injection probing is the framework that we will use to test most of the detector elements that we suspect of being sources of scattering noise. Elements other than the chamber walls that we plan to test include: chamber viewports and windows, as they have previously been identified as potential scattering noise sources [2].

Other parts within the tube that may contribute to scattering noise include the baffles that are meant to prevent excess scattering off of the walls of the chambers, as well as other, secondary mirrors within the apparatus. However, these objects will be more difficult to test for scattering noise, as we will be unable to directly vibrate them using our previous injection techniques. It is possible that they could be excited using some of the aforementioned secondary coupling effects, should they be discovered during the course of our other testing.

Work Plan/Schedule

It should be noted that how long is spent analyzing each part of the detector is highly dependent upon whether or not we find them to be significant sources of scattering noise, so this schedule is highly subject to change.

Week 1: Introductory preparations, familiarization with the facility, and administrative preparations.

Weeks 2-3: Collect data for the chamber walls.

Weeks 4-5: Analyze data for the chamber walls, check for coherence, potentially take new data to determine location dependence for the chamber wall scattering level.

Week 6: Collect data for viewports on HAM 6 chamber.

Week 7: Analyze data for the HAM 6 chamber viewports.

Week 8: Collect data for BSC chambers' ports.

Week 9: Analyze data for BSC chambers' ports.

Week 10: Compile data for end of session, create final reports.

References

[1] B. Abbott et al. LIGO: The Laser Interferometer Gravitational Wave Observatory. Rep. Prog. Phys, 72(7):076901, 2009.

[2] Effler, A., Schofield, R., Frolov, V., Gonzalez, G., Kawabe, K., Smith, J., Birch, J. and McCarthy, R. (2014). Environmental Influences on the LIGO Gravitational Wave Detectors during the 6th Science Run.

[3] J. Abadie et al. Search for gravitational waves from compact binary coalescence in LIGO and Virgo data from S5 and VSR1. Phys. Rev. D, 82(10):102001, 2010.

[4] J. et al Abadie. Predictions for the Rates of Compact Binary Coalescences Observable by Groundbased Gravitational-wave Detectors. Class. Quant. Grav., 27(17):173001, 2010 .

[5] Thorne, K. (1989). Light Scattering and Proposed Baffle Configuration for the LIGO.