Understanding and improving the accuracy of Advanced LIGO Calibration

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1. Background

In 1915, Einstein published his General Theory of Relativity (GR). This theory and his following papers predicted the existence of gravitational waves (GWs). In 1993, a Nobel Prize went to Hulse and Taylor [2] who discovered pulsar system losing energy at the same rate predicted by GW emission, and thus implying the existence of GWs. Direct detection of GWs first occurred in 2015 at the Advanced LIGO detectors [1].

GW astronomy lets us observe events that are not visible in the electromagnetic spectrum, like black hole mergers and other relativistic systems. It also lets us test the theory of GR in new ways and offers the possibility of seeing past the epoch of recombination. This would let us look back in time to the universe's inflationary period, a current impossibility with electromagnetic radiation. Because of the sorts of observations GWs would allow, detecting them has been an exciting goal for the past few decades.

Though work on building instrumentation to detect gravitational waves started in the 1960s, it was not accomplished until 2015 by the advanced Laser Interferometer Gravitational Wave Observatory (aLIGO). The discovery had to wait until detectors sensitive enough to the minuscule amplitudes of GWs could be built. At these very small scales (on the order of 4×10^{-20}m [1]), careful calibration has to be maintained to accurately associate the frequency response of the detector with the motion of aLIGO's optics.

The first GW has only recently been detected; the universe as illustrated by GWs is an emerging perspective in astronomy. Observing things in the universe for the first time is exciting and impactful, but verification that the detections are actually real is incredibly important. Publishing uncertain/inaccurate detections can confuse and delay our understanding of the universe, but can happen in the excitement of new and big discoveries. Consequently, good calibrations of instrumentation is vital if we are to be confident about collected data and use it to understand how our universe works.

2. Objective

This summer project is about understanding and the accuracy of the calibration of the aLIGO detectors for future GW detections. Currently, aLIGO has a calibration uncertainty of less than 10% in amplitude and 10 degrees in phase from from 20 Hz to 1 kHz [3]. The goals of this project are first to understand the calibration methods used for aLIGO and their uncertainties, and second to understand how to estimate the effects of this calibration uncertainty in two contexts: on astrophysical parameters such as the source distance, sky location, and the progenitor masses and spins, and also on impact on precision tests of GR. The project will conclude with calculations describing how the potential improvements of calibration could improve the accuracy of determining parameters in these two contexts.

3. Approach

To begin, I will conduct a small literature review concerning aLIGO instrumentation and calibration methods prior to and in the first weeks of the internship. Since the goal of this project is to understand how potential calibration improvements can improve our ability to extract astrophysical and beyond-GR parameters, most of my time will be spent on propagating calibration uncertainties in astrophysical and GR-testing errors. The timeline for this project is outlined in Table 1.

Table 1: Timeline

Dates	Focus
June 14th - June 28th	Literature review and selection of calibration focus
June 28th - July 12th	Understand the calibrated response and the calibration uncertainty; learn how to modify the current models.
July 12th - July 26th	Develop methods to propagate calibration uncertainty to the extraction of astrophysical parameters from observed binary black hole events.
July 26th - August 9th	Quantitatively evaluate the systematic and statistical errors on astrophysical and beyond-GR parameters from calibration uncertainties, and identify the contributions to the calibration uncertainty that most affect these errors.
August 9th - August 19th	Prepare abstract, oral presentation, and written report

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