LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Developing an In-Air IR Test Facility for Next-Generation Wavefront Control

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1 Introduction

In 1893, gravitational waves were first proposed by Oliver Heavyside when noting the similarities between the inverse square laws of electrical charges and gravity; a little over a decade later, Henri Poincaré proposed that these possible waves would have to move at the speed of light [4, 5]. However, it was not until Einstein's Theory of General Relativity in 1916 that gravitational waves were predicted by a physical model [3]. In essence, gravitational waves can be described as ripples in spacetime caused by accelerating massive objects. The strongest, and thus most measurable, gravitational waves are caused by huge astronomical events like colliding black holes and neutron stars, as well as supernovae. Unlike electromagnetic radiation, gravitational waves only weakly interact with matter between source and detection, making them invaluable tools for understanding the mechanisms of their sources. After Einstein's predictions, however, the existence of gravitational waves was hotly debated, even by Einstein himself. It took until 2015 for gravitational waves, caused by two colliding black holes, to be directly detected at aLIGO (advanced Laser Interferometer Gravitational-Wave Observatory).

aLIGO's construction, building on the initial LIGO model, began in 2008. LIGO is essentially a set of two massive Michelson interferometers with 4 km long perpendicular arms, forming an L-shape (see Figure 1). In essence, lasers are sent through the arms, reflected off mirrors at their ends, and then recombined at a photodetector between the two arms. As gravitational waves pass, they stretch spacetime in one direction, causing an interference pattern between the lasers in the two arms. This interference pattern can be measured to understand the character of the wave and, by extension, the event that produced it. However, the precision needed to detect gravitational waves means any noise can be detrimental to results. The work transitioning from LIGO to aLIGO and current work has been focused on reducing noise. The greatest source of noise in aLIGO is quantum noise [2]. One way to decrease quantum fluctuations, however, is to increase the power used: photon shot noise decreases as the number of photons increases (by a factor of $\frac{1}{\sqrt{N}}$).

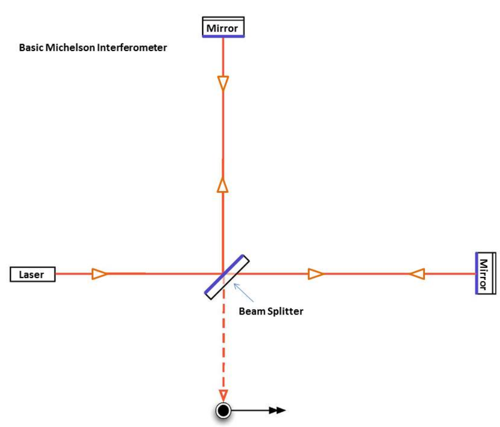

Figure 1: Basic diagram, from the LIGO website [8] showing the Michelson interferometer setup that is the basis of the design of LIGO.

Unfortunately, increasing the power can introduce or amplify other sources of noise. One such example is from defects that are physically present in mirrors from their fabrication, particularly point absorber defects [2]. Our project for the summer of 2022 will be to create an in-air facility with a setup to test adaptive optics that counteract these and, ideally, other thermally-induced mirror deformations in aLIGO's mirrors. The key components of the facility include an infrared-detecting camera, a thin screen to act as a test mass, and the annular ring heater developed by Dr. Richardson and his colleagues [6].

2 Objectives

In order to produce extremely low loss laser cavities, this project seeks to:

1. Construct an in-air optical test facility to allow for the testing of infrared adaptive optics systems.
2. Develop Python code to collect raw data from the infrared sensor in order to test current and future wavefront controlling technology.

3 Approach

The first few weeks of this project will be dedicated to setting up the in-air optical table system using a simple triangular optical setup with the ring heater, IR-absorbing thin screen, and the infrared camera, as in Figure 2. The ring heater, which has an inner diameter of 0.34m, will allow for manipulation of the radiation that hits the 0.5m diameter IR absorbing screen (in place of the 0.34m test mass in the aLIGO system). The screen, which is 0.1mm thick, is thin enough that the infrared-sensitive camera will be able to detect and map the effects of the ring heater on the test mass based on the image of the back of the screen (the width of the screen is negligible to understanding the infrared pattern).

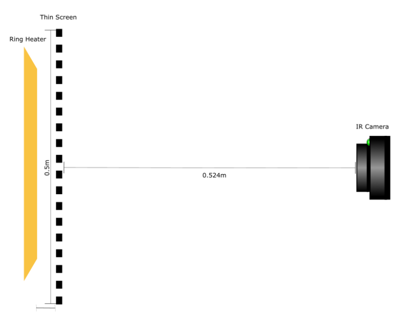

Figure 2: Optical Diagram of the In-Air IR Test Facility Setup

One key component of this system is the infrared camera, which uses uncooled microbolometers to detect infrared radiation based on the changing electrical resistance [9]. The microbolometers, sensitive to IR, are arranged in a 400 x 400 array in the camera used for this iteration of the in-air test facility (the Teledyne FLIR A50/A70). This camera has a 51° x 39° field of view. In order to allow the camera to capture stray light bouncing off the test mass, 0.5m is defined as the desired diameter of the camera's view. Using the hFOV, 51°, it is clear that the camera must be 0.524m from the screen to contain the entire 0.5m area in it's FOV while still maximizing the FOV (as in Figure 3).

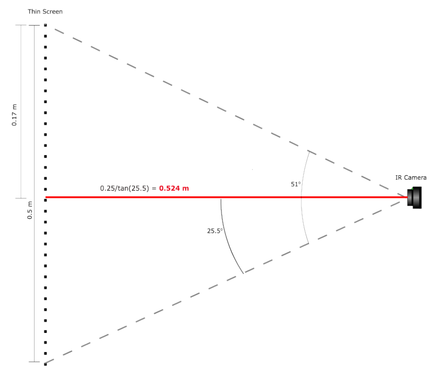

Figure 3: FOV Calculation to Determine Camera Distance from Screen

The second portion of this project will be to create Python code in order to collect data from the IR camera. Building on the existing API, this code will allow for the camera settings to be configured and to collect data characterizing the pattern added to the thin screen by the ring heater. In particular, the Python code will allow for a snapshot of the screen to be taken at a specified time, exporting all relevant data, and for a stream of snapshots to be taken over some period of time, with all relevant data exported. This code will be used for all upcoming work with this camera with the end goal of using the camera to determine the best heating pattern from the ring in order to mitigate power loss from the point sources in aLIGO's mirrors.

4 Timeline

Week 1: Finalize optical layout.

Week 2-3: Construct the facility, particularly the installation of the camera and related optomechanics, the ring heater, and the thin screen. Align these optical elements.

Weeks 4-7: Develop the Python code to collect data from the camera's array of microbolometers by building on the existing API for calibration.

Weeks 8-10: Test and refine the code and setup to allow users to calibrate the camera and collect data both continuously and as a snapshot.

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