LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Scattered Light Study of Advanced LIGO in Observation Run 2

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1 Introduction

The Laser Interferometer Gravitational-wave Observatory (LIGO) is a system of sensitive instruments designed to detect the weakest physical signal, the gravitational wave (GW) by interferometry of coherent monochromatic light. According to Einstein's theory of general relativity, gravitational waves can be understood as a propagating disturbance of space-time fabric caused by, for example catastrophic astrophysical events such as the merging of a pair of black holes or neutron stars. Such disturbance would cause a strain in space on the scale of 10^{-21}, which is an incredibly small quantity to measure directly. Therefore, Michelson interferometry technique shown in Figure 1 is employed in LIGO to pursue detections of the infinitesimal strain.

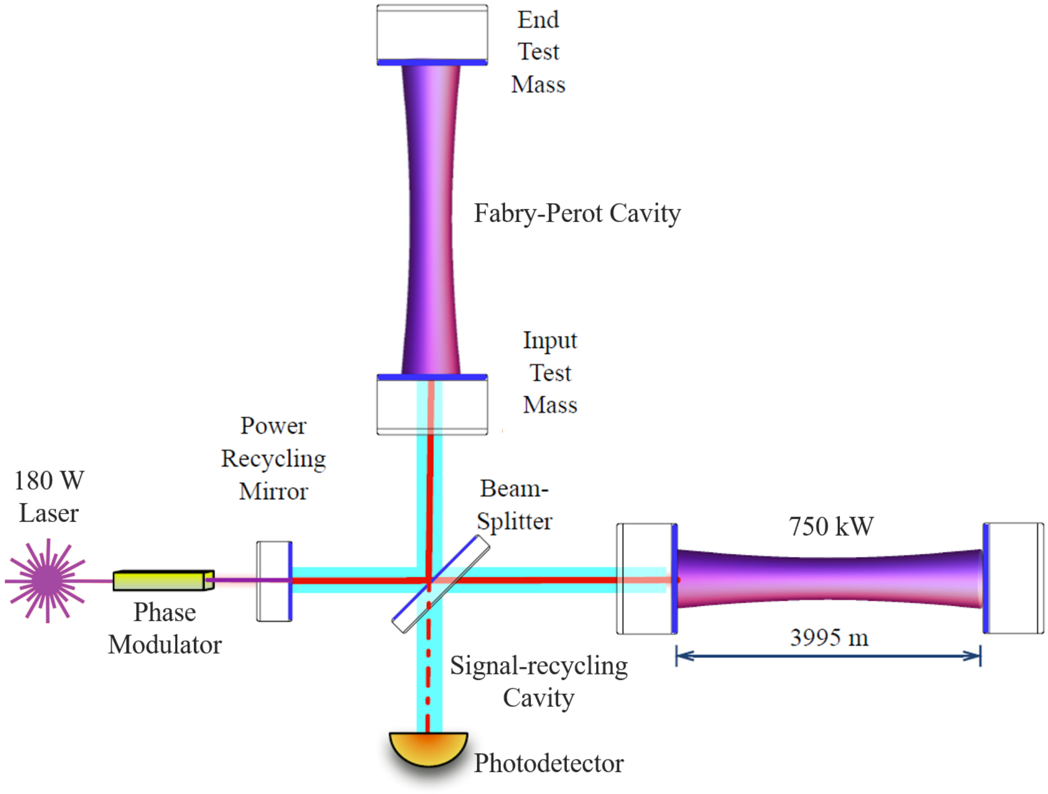


Figure 1: Schematics of Michelson interferometer used in LIGO [1].

For the past ten years, LIGO has been upgraded several times to enhance its sensitivity, and the latest one named as Advanced LIGO (aLIGO) is capable of measuring strain of 10^{-21} with frequency band of 10-5000 Hz [2]. The Advanced LIGO is still limited by the theoretical noise budget presented in Figure 2. The theoretical noise budget has not been achieved by aLIGO, and scatter is believed as one of the main noise sources that limit our current sensitivity.

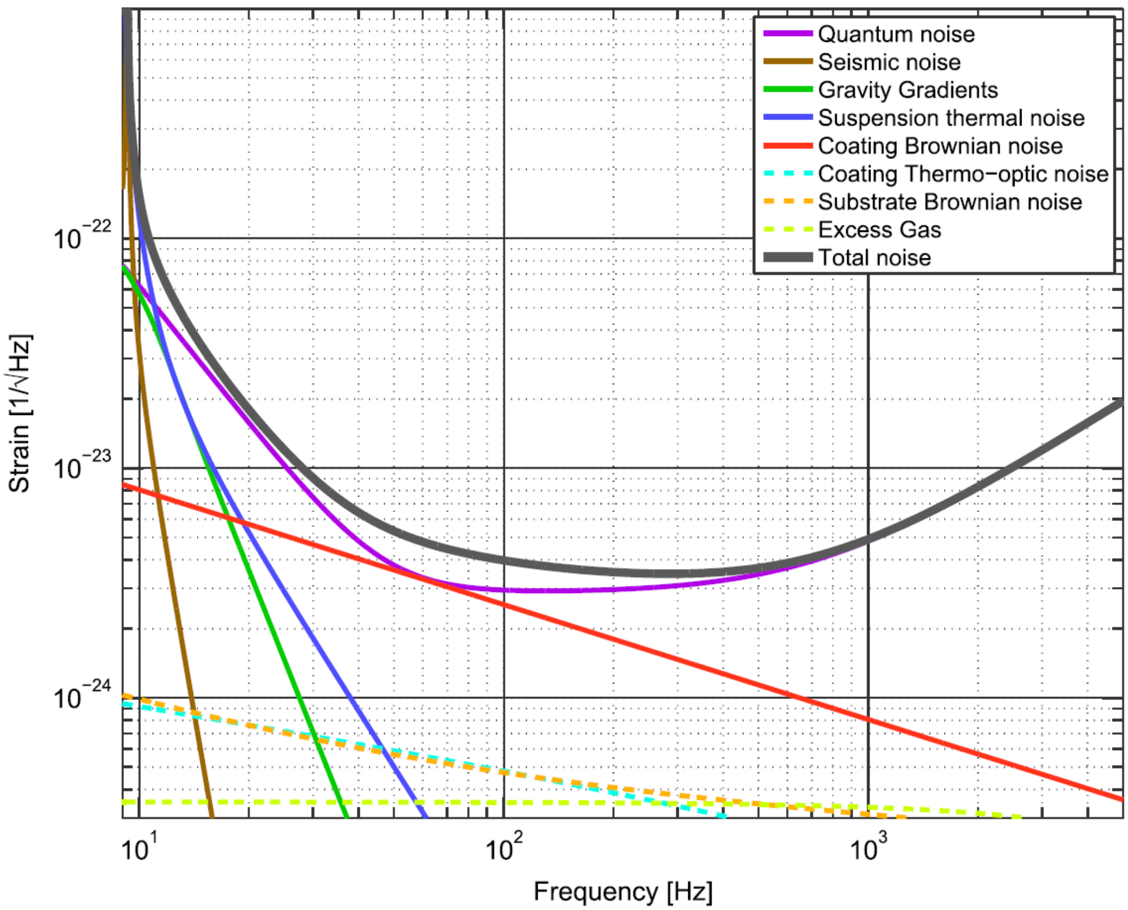


Figure 2: Principal noise terms for the nominal mode of operation of aLIGO [2].

The main focus of this proposed research will be investigating the scattered light in the Fabry-Perot (FP) cavity of interferometer. Once undesired photons scatter from non-isolated surface and rejoin with main beam, they will produce unwanted phase fluctuation relative to the main beam [2]. Ottaway *et al* [3] modeled the theoretical impact of scattered light and demonstrated its compromising effect on the performance of aLIGO at low frequencies (∼10 Hz) during the highest microseism periods (ASD of seismic motion of $\sim 1\ \mu\mathrm{m}/\sqrt{\mathrm{Hz}}$). The understanding of light scattering with experimental data would be key to identify its contribution to the noise of detector.

2 Proposed Research

To prevent scattered photons from re-entering the main beam of interferometer, multiple light baffles are mounted on beam paths as shown in Figure 3.

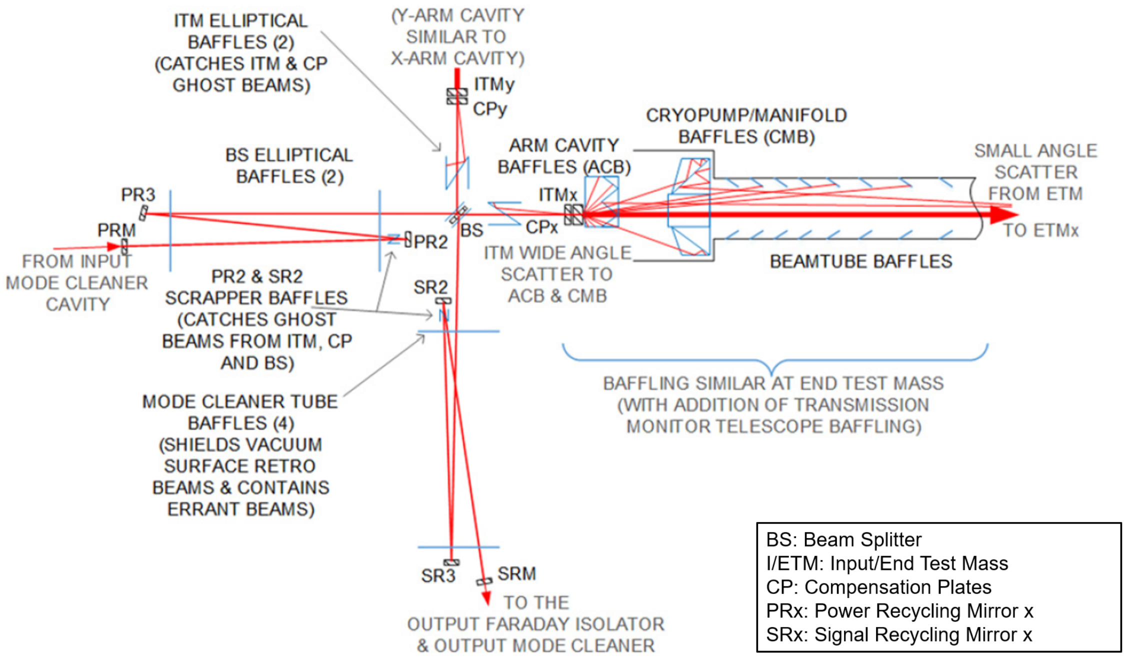
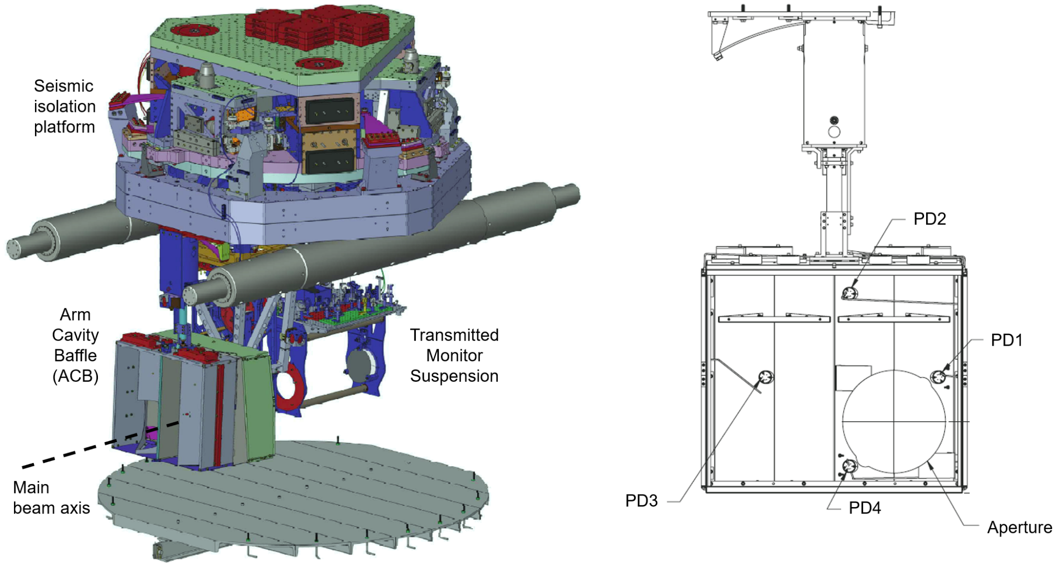


Figure 3: Locations of scattered light baffles in the LIGO optical configuration [2].

Those beamtube baffles mounted on the sidewalls of the ultra-high vacuum cavity as well as the cryopump/manifold baffles are meant to block the large-angle scatter. The small-angle scatter from the far test mass (4 km away) is caught by the arm cavity baffle (ACB) placed in front of each test mass optic [2]. Since the GW signal is obtained by measuring the differential arm-length, the scattered light in the arm cavity would have higher impact on the output signal measurements. More details of ACB are pictured in Figure 4.



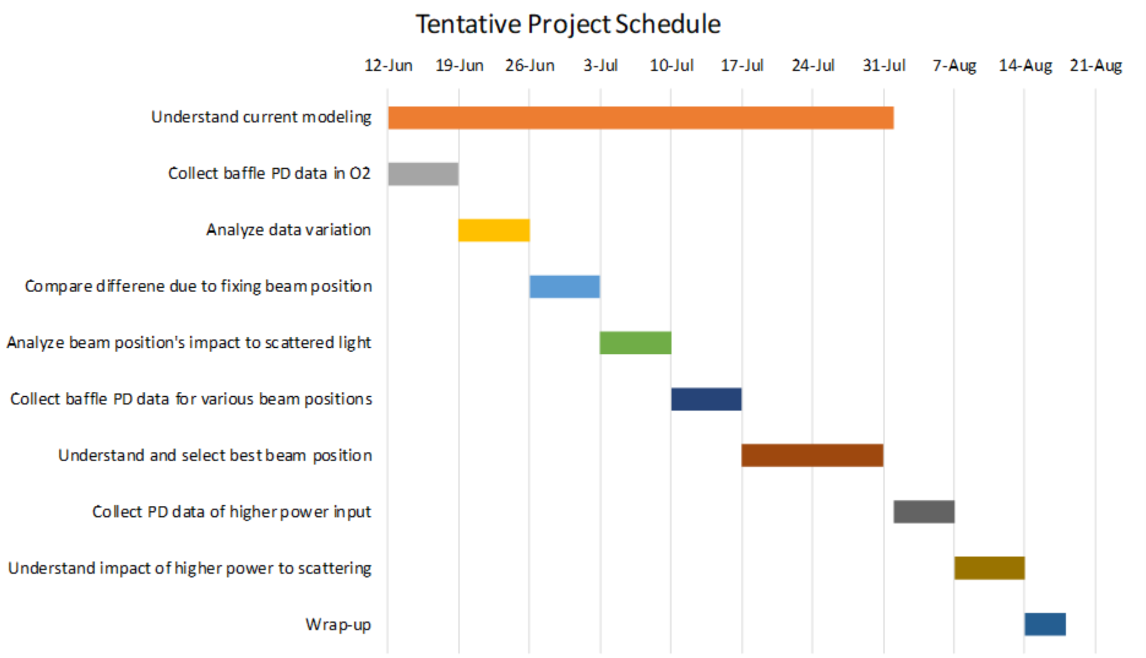
(a) (b)

Figure 4: (a) ETM full chamber drawing [4] and (b) back view of the baffle on ETMy with four photodiodes (PD) annotated [5].

The four PDs mounted on the baffle measure the intensity of low-angle scattered light from the other test mass. In the Observation run 2 (O2) from 2016/12 to 2017/08, the position of main beam has been fixed on the ETMs but not directly on the ITMs, and we can see if ITM baffle PD's data measuring scattered light from ETM varies over time. If the scattered light from ETM was constant over O2, then the data can be used to cross-calibrate beam positions on the test masses. We will move the beam position around the cavity mirror and measure the scattered light at each corresponding position. If not, it is necessary to investigate possible factors that influenced the scattering.

In addition, the input laser power will be increased in the future to improve the sensitivity at high frequencies, and the scattering effect under higher cavity power is still unknown. We will collect baffle PD data under higher cavity power and quantify its impact on the light scattering. The baffle PD measurements would be analyzed and compared with models such as Static Interferometer Simulation (SIS) [6] or Bi-directional Reflectance Distribution Function (BRDF) [7]. Such analysis would help understand and predict the noise contribution of the scattered light.

3 Work Plan



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