Investigating Observational Improvements For Future Gravitational-Wave Detectors Using Tuned Interferometry

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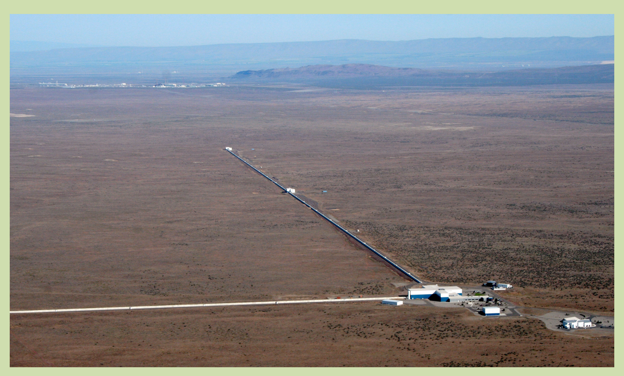
Abstract

The goal of this research project is to analyze potential improvements to the Laser Interferometer Gravitational-Wave Observatory (LIGO) by adjusting the position (tune-phase) as well as the transmissivity of mirrors located in the instrument. This allows for frequency-dependent sensitivity improvements for gravitational wave (GW) measurements – just like putting a filter on a telescope!

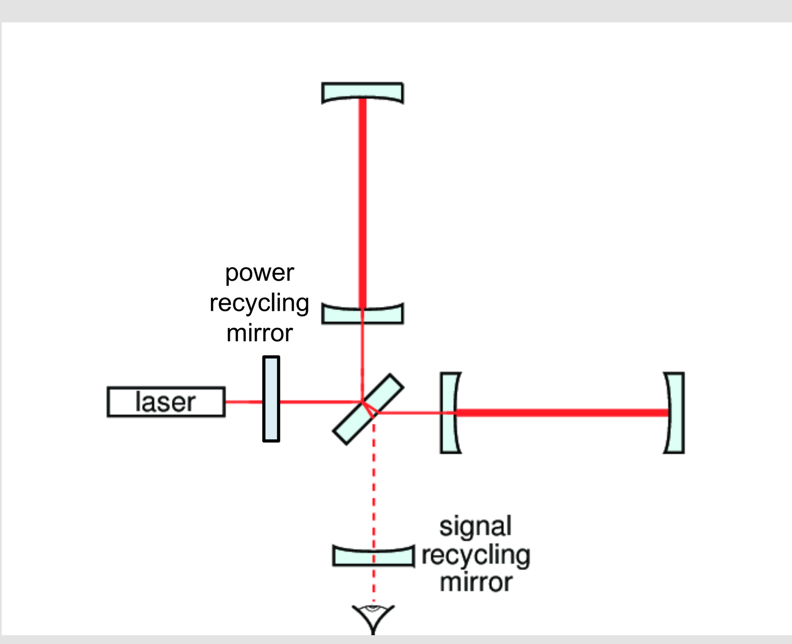
Aerial pictures of LIGO Hanford, WA (left) and LIGO Livingston, LA (right)



Introduction

The instrument currently in use at LIGO is an extremely large Michelson Interferometer with Fabry Perot cavities. In short, it is a system of five mirrors, a beam splitter, and a laser.

A Michelson interferometer with Fabry Perot cavities, signal recycling mirrors, and power recycling mirrors. Pitkin et al. 2011

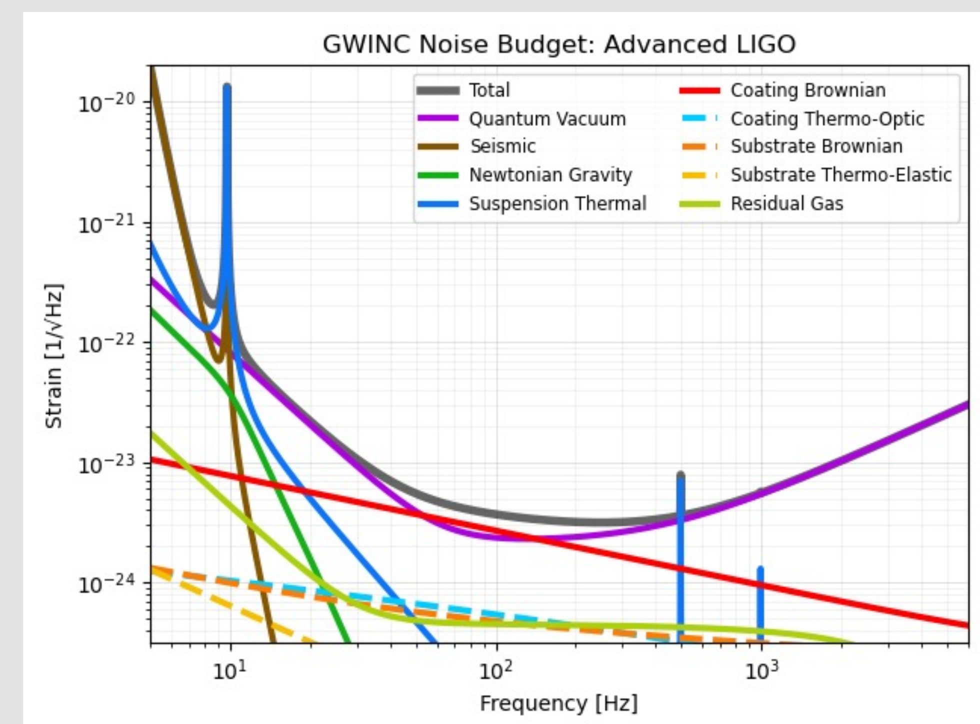


The laser is split and sent down two "legs," perpendicular to one another with lengths of 4km. The light then reflects around 300 times in the Fabry Perot cavities. The further the laser travels, the more sensitive LIGO is. The power recycling mirror reflects light that has already traveled through the legs back into them after their 300 cycles. When a GW interacts with the laser, it slightly delays the light, causing interference. The light then exits the legs into the photodetector. The signal recycling mirror clarifies the signal received by the photodetector.

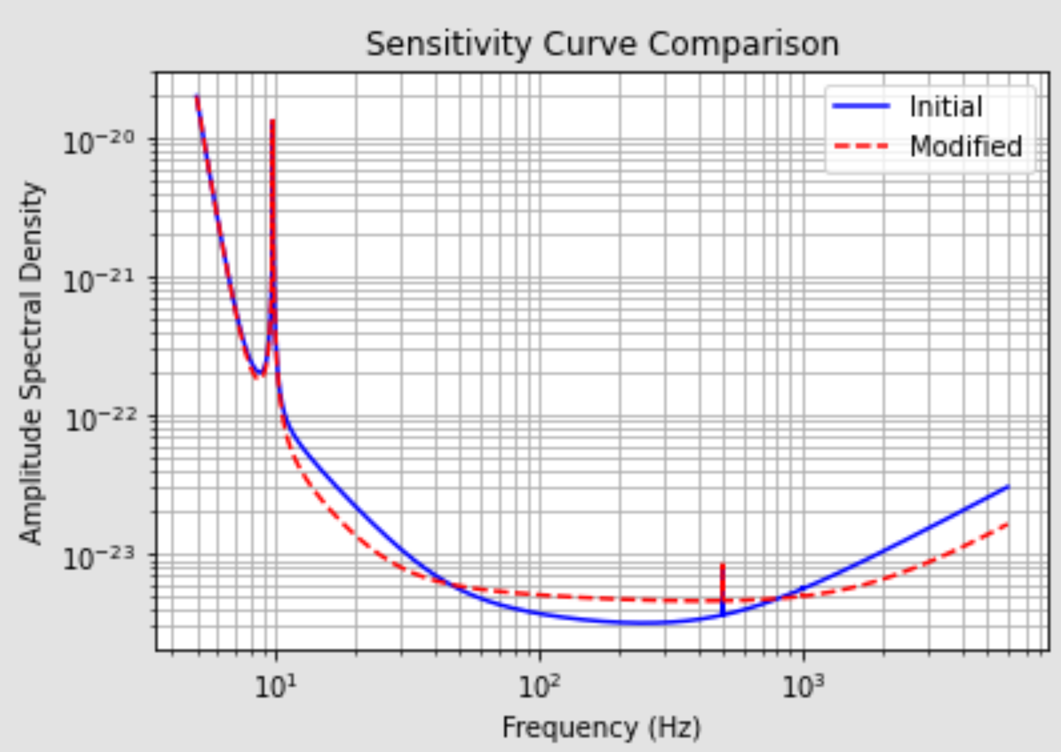
Results

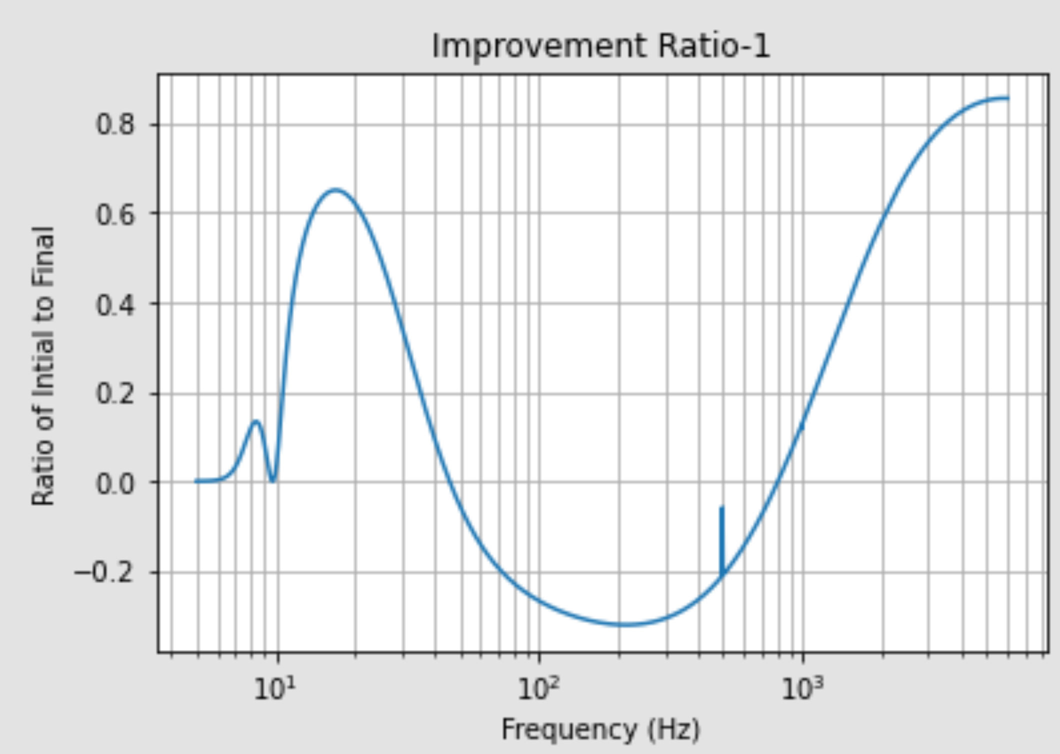
This project is developing the optimum positions and transmissivities of the mirrors and finding the best ranges of improvement based on combinations of the two. Other aspects of the project operating in parallel aim to construct an apparatus which would be capable of executing the tune-phase changes whilst dealing with the restriction of the mirrors being in a vacuum that cannot be easily broken and reinstated. In order to determine the usefulness of ranges of improvement we used the spin-down limits of 196 usable pulsars from Abbott et al. 2021 and noted how many more pulsars would be able to be collected depending on the selected tune-phase and transmissivity combination.

The sensitivity of Advanced LIGO as well as the noise curves that form the sensitivity curve

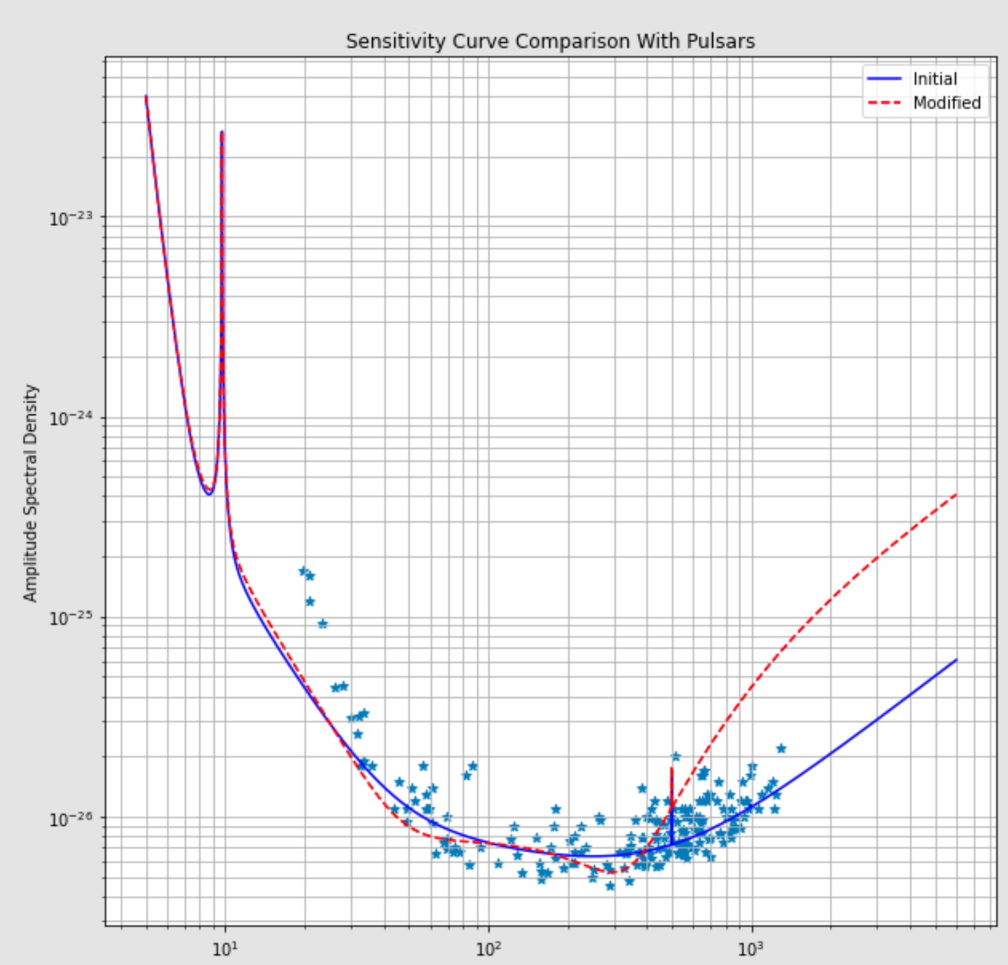


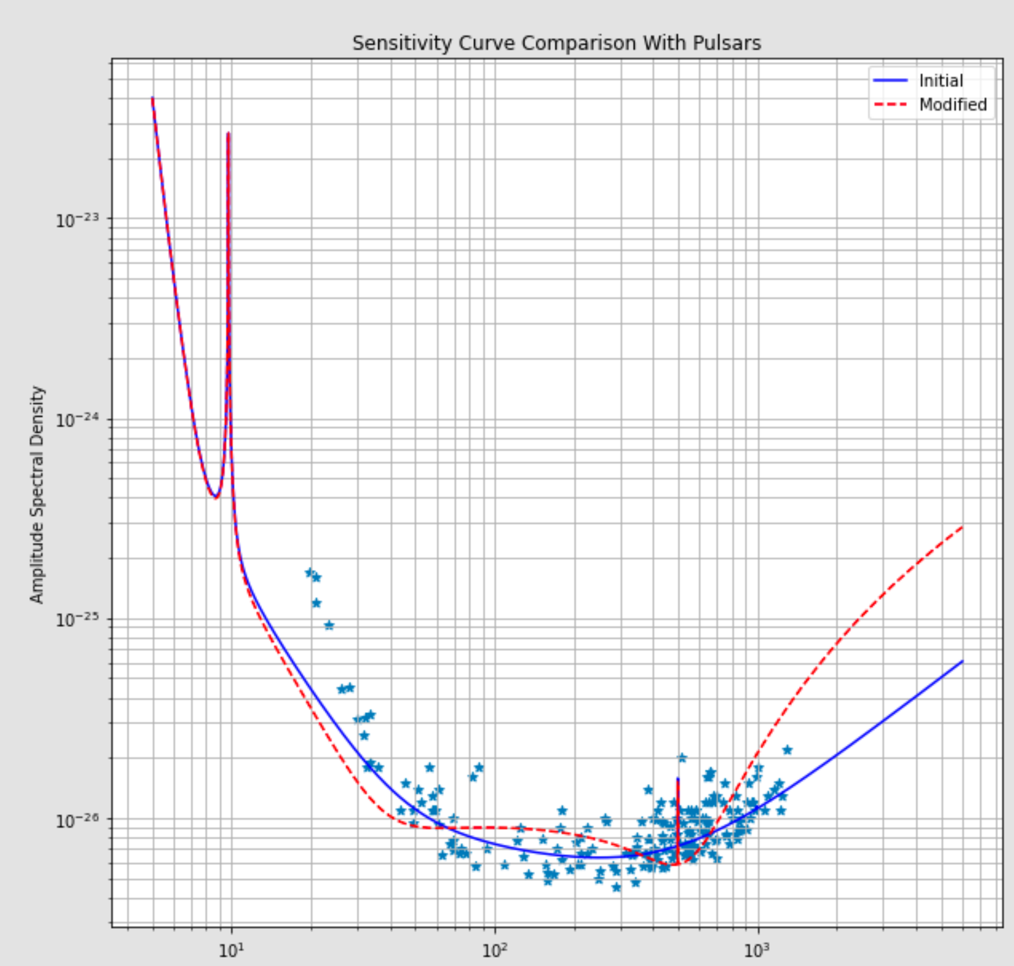
Sample outputs, on the left is the modified graph overlayed on the graph of the current sensitivity, on the right is the percentage improvement compared to the current sensitivity based on frequencies. Both graphs have a tune-phase of 0.4 and a transmittance of 0.1.





Actual outputs, both are the modified graphs overlayed on the graph of current sensitivity, the blue star shapes are spin-down limits of 196 usable pulsars from Abbott et al. 2021. (left) tune-phase of 0.25 and transmittance of 0.15 (right) tune-phase of 0.15 and transmittance of 0.1.

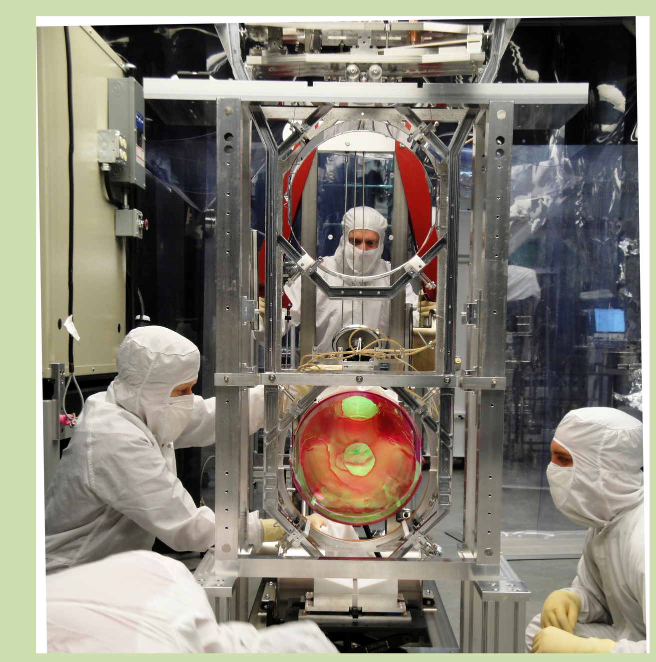




Overall Goal

LIGO is so sensitive that the fluctuations in the density of the earth affect the clarity of the signal detected. One of the future possible projects for gravitational-wave astronomy would be to build an interferometer in space, it would allow the legs to be even longer than before, and seismic interference would not be a factor. The name of that project is Laser Interferometer Space Antenna (LISA). With the current project though we aim to improve the current instrument.

One of the large optic suspensions used in LIGO



Future Steps

We have edited pygwinc so that it calculates the frequency ranges where improvements exceed 5%. We are currently working on compiling all the ranges for all the possible tune-phase and transmissivity combinations. Once that is complete, we plan to find the ranges with the best ranges for improving the number of pulsars detected. Once the best ranges are collected, we will then focus heavily on the prototype of the actuator in order to hit the desired tune-phases.

The current actuator prototype designed and constructed by Serena Determan

Acknowledgements

Abbott et al. 2021, LIGO Laboratory, Pitkin et al. 2011, and Serena Determan