Laser Frequency Stabilization for LISA

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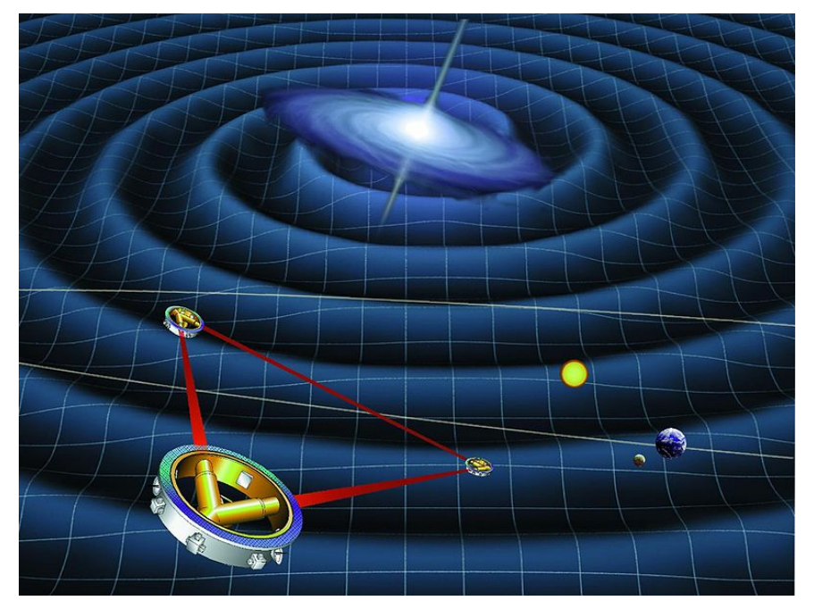
ABSTRACT

This research focuses on laser ranging developments for LISA (Laser Interferometer Space Antenna), a planned NASA-ESA gravitational wave detector in space. LISA will utilize precision laser interferometry to track the changes in separation between three satellites orbiting 5 million kilometers apart. Specifically, our goal is to investigate options for laser frequency stabilization. Previous research has shown that an optical cavity system can meet LISA's stability requirements, but these units are large and heavy, adding cost to the implementation. A heterodyne Mach-Zehnder interferometer could be integrated onto LISA's existing optical bench, greatly reducing the weight, provided the interferometer meets the stability requirements. On this poster, we describe a performance comparison between an optical cavity and a Mach-Zehnder interferometer, by measuring the relative phase of stabilized lasers from the two systems. This project's results will determine whether a heterodyne Mach-Zehnder is suitable for LISA.

INTRODUCTION

What is LISA?

LISA is a system of 3 spacecraft planned to detect gravitational waves by using lasers to measure the distance between the spacecraft. Gravitational waves are invisible ripples in spacetime that radiate from large accelerating masses such as colliding supermassive black holes. They have yet to be directly observed, but they would make the three spacecraft of LISA change distance from each other by as little as a tenth of the diameter of a hydrogen atom.



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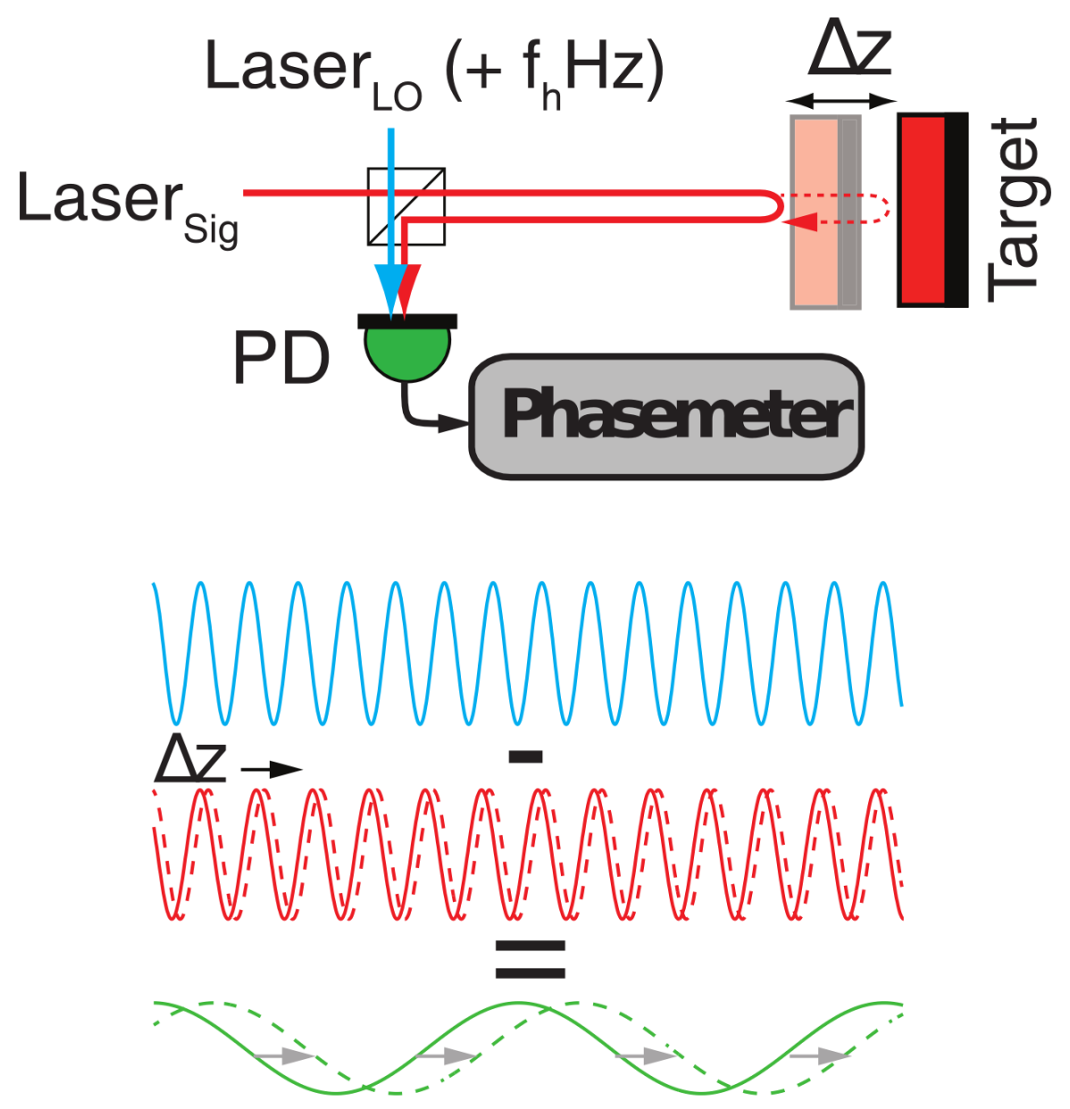


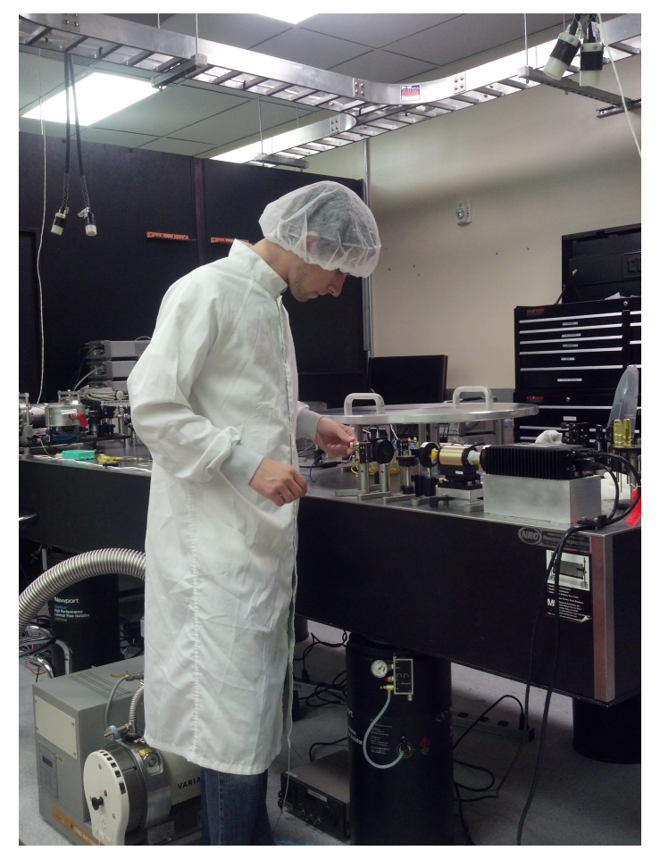
How do lasers measure distance?

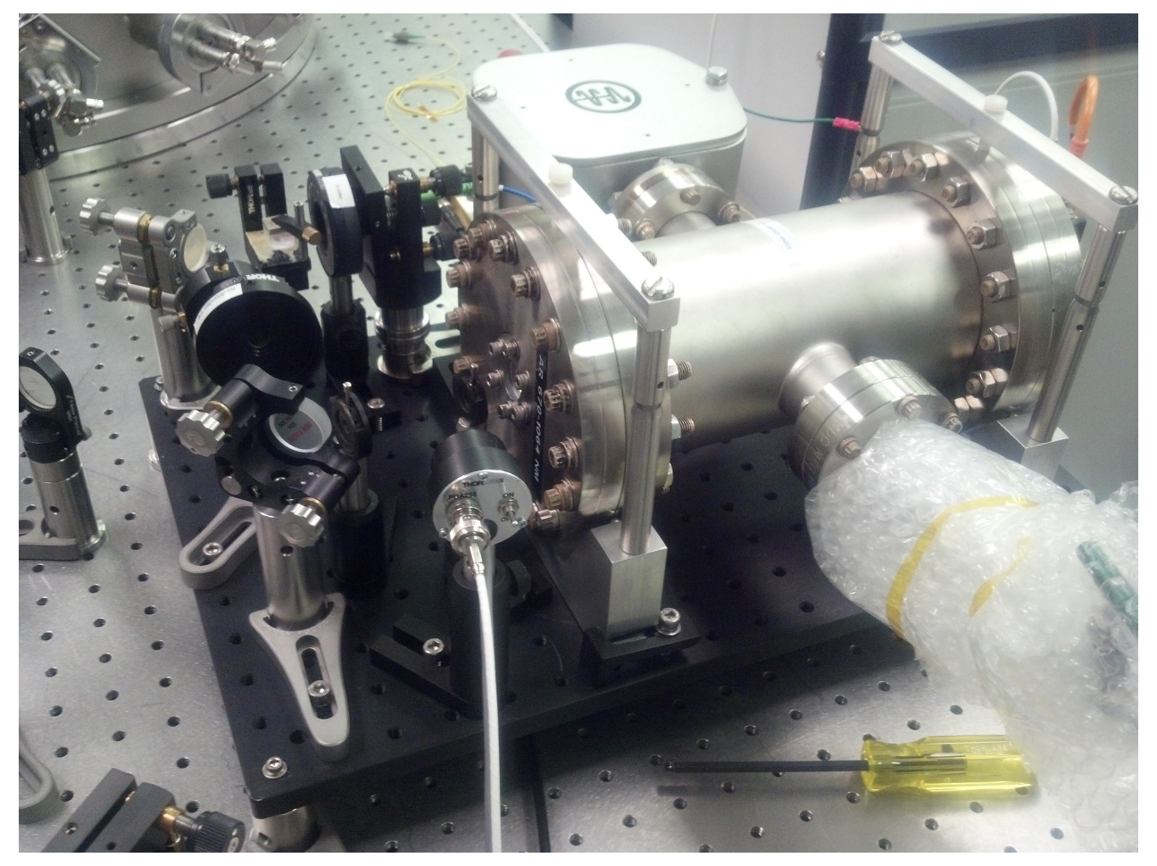
LISA will need to be able to measure the distance between the spacecraft to a precision better than 1 micron. Near-infrared lasers are in a good range for this, but the wavelength must be very stable.

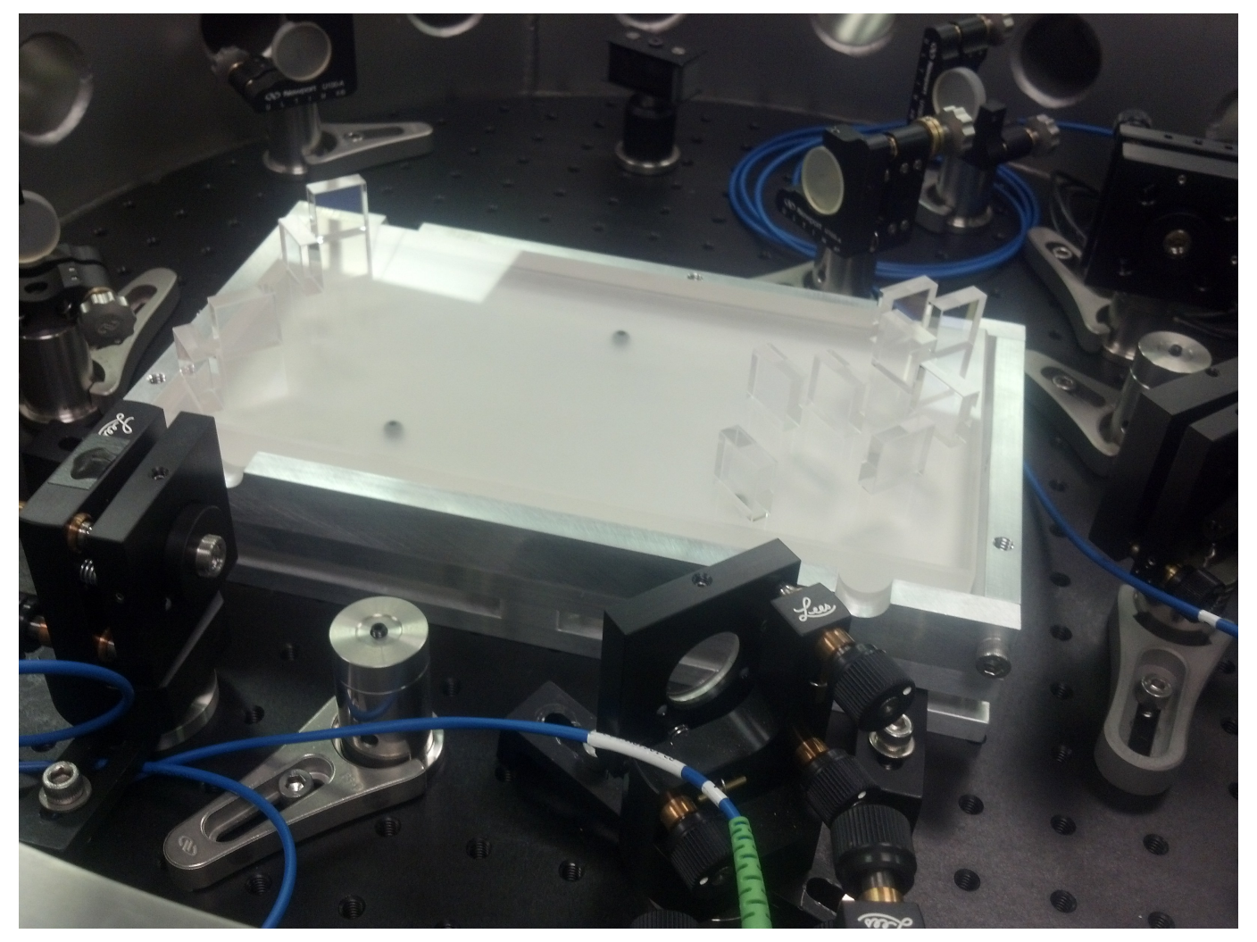
Interferometers measure distance by interfering two laser beams. If one path is slightly longer than another, the two beams will be out of phase when they recombine. In a heterodyne (two-frequency) interferometer, two optical fields come in and out of phase periodically, giving rise to an intensity 'beat-note'. The phase of this beat-note is sensitive to changes in displacement.

The frequency of a laser will naturally fluctuate due to thermal changes. The laser can be stabilized by measuring the distance of a very stable length, and attributing any fluctuation in that measurement to the laser's frequency variation. A computer system can then control the frequency accordingly.

The heterodyne Mach-Zehnder (MZ) interferometer, which stabilizes two lasers at once, must perform well enough to meet the precision requirements of LISA. The benefit of the MZ is its practical efficiency: it can make its stability measurements on the same optical bench that LISA uses to measure the distance between the spacecraft.

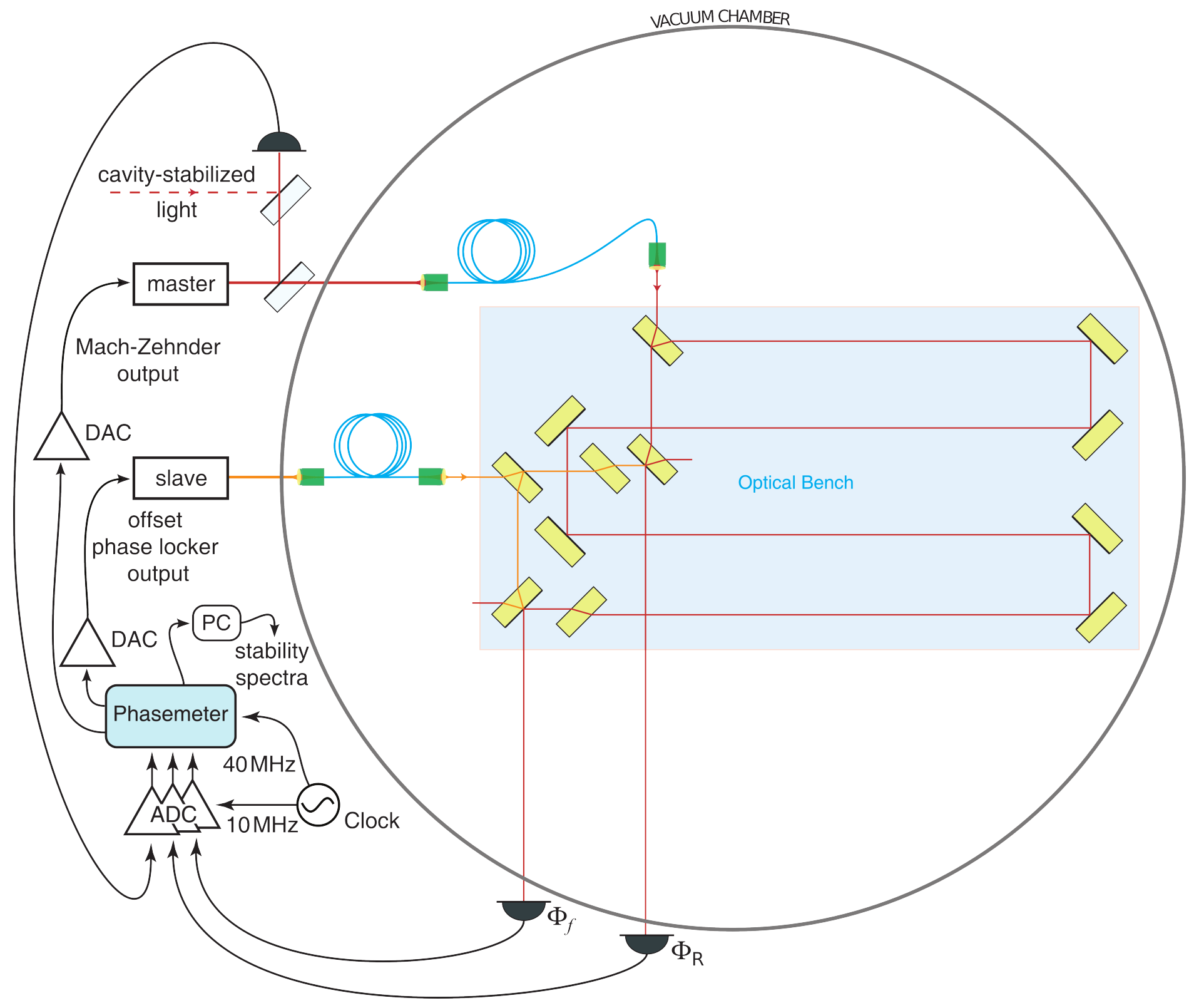






METHODS

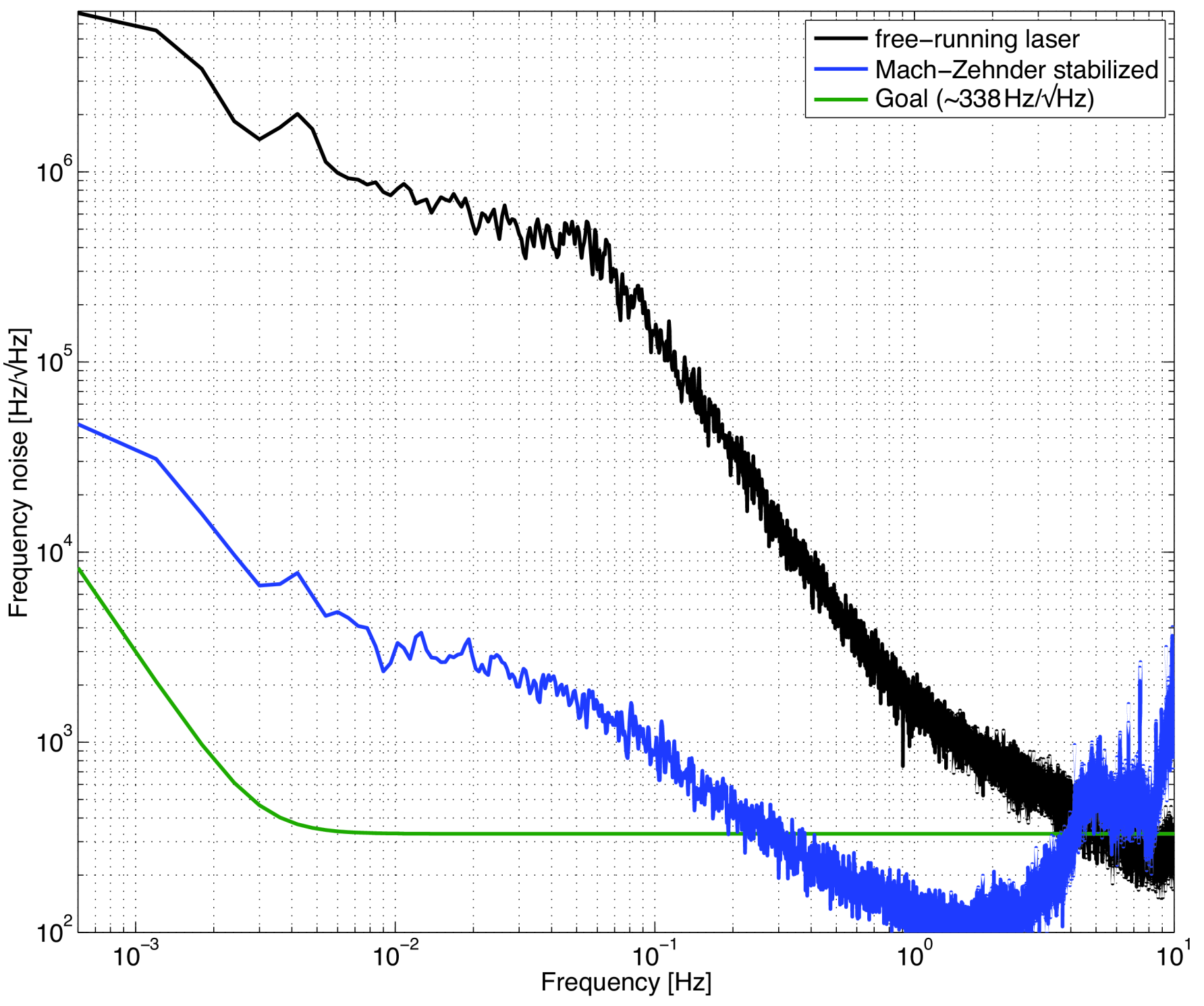
Two lasers are aligned onto the MZ optical bench, while another is aligned to a reference cavity. The three laser frequencies are brought to within megahertz of each other before activating the computer control systems. Phase information from the MZ is measured by subtracting two optical paths on the bench: a short path, which subtracts all noise occurring prior to the interferometer, and a long path, which forms the stable length reference. Light from one of the MZ lasers is combined via optical fiber with the cavity-stabilized light to create a beat-note. To measure the relative stability of the systems, we measure the frequency of this beat-note over time.



RESULTS

If the stability was identical between the MZ and the reference cavity, the measured beat-note frequency would be constant. The amount of noise in the beat-note frequency quantifies the difference in the stability between the MZ and the cavity.

The figure at right shows prior performance results for the MZ. The free-running trace shows the beat-note stability of an uncontrolled laser, while the MZ trace demonstrates the suppression of laser frequency noise. The previous experiment failed to reach the performance goal, motivating the further investigations performed in this project.



CONCLUSION

This approach aims to make the LISA mission simpler and more cost-effective, and by doing so contribute to the science of gravitational waves. Observations of gravitational waves will help answer many open questions about our universe, and will enable further study of black holes, General Relativity, and the structure of galaxies.

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