Einstein Telescope Infrastructure Consortium (PNRR ETIC IR000004, CUP I53C21000420006)

XXXVIII cycle Ph.D. course in Physics

Second Year Report

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Research Activity

In the second year of my Ph.D I mainly focused on the EPR experiment, an innovative method to reduce quantum noise in next generation of gravitational wave detectors, such as Einstein Telescope. This technique involves injecting two EPR (Einstein-Podolsky-Rosen) squeezed fields into a small-scale suspended interferometer, called SIPS (Suspended Interferometer for Ponderomotive Squeezing). My research centers on SIPS, designed to operate in the same frequency band as large-scale gravitational wave detectors, like Virgo. It is sensitive to both radiation-pressure noise and shot noise at different frequencies, making it an ideal testbed for demonstrating the EPR principle.

In the first part of my second year, I conducted detailed simulations using FINESSE software to advance the optical cavity dynamics of SIPS. Specifically, I focused on key aspects of optical systems such as resonance, stability and feedback control. My first simulation involved a two-mirror optical cavity with a 1.25 W laser input, where I investigated the resonance behavior by tuning the input mirror and observing the resulting resonance peaks. This setup allowed me to analyze how cavity components interact and respond under varying conditions, which is essential for achieving optimal resonance stability.

Then, I examined the optical spring effect in a Fabry-Perot cavity. By slightly detuning the cavity and applying a force to the end mirror, I observed how both mirrors responded to external forces. This study clarified how an optical spring can contribute to system stability, which is critical in suspended interferometer systems.

I also explored the Pound-Drever-Hall (PDH) locking technique using a two-mirror cavity configuration. This method employs an Electro-Optic Modulator (EOM) to phase-modulate the laser, facilitating the stabilization of the laser frequency locking to a stable cavity, or vice versa. By utilizing a modulation frequency, I generated an error signal to dynamically adjust the input mirror's position, thus maintaining resonance within the cavity.

Additionally, I performed a radiation pressure simulation, where a single mirror suspended as a pendulum was subjected to a modulated laser beam. This setup illustrated how radiation pressure influences mirror motion, highlighting the delicate balance required in optical systems where even minor forces can impact stability.

Furthermore, I worked on the implementation and testing of local control for the suspended optics of SIPS, including the dummy end mirror, as well as testing its alignment and stability. These tests are conducted in the laboratory of La Sapienza in Rome, where the SIPS setup is physically located. Specifically, I began by studying an existing script in LabVIEW and connected a PXI system to a PC running LabVIEW software to process signals in real-time. Amplifiers boost sensor signals, which are digitized by an ADC (Analog-to-Digital Converter). LabVIEW then calculates corrections, and a DAC (Digital-to Analog Converter) sends analog outputs to coils that adjust the mirror via magnets for alignment in the Fabry-Perot cavity.

In parallel with my work on SIPS, I collaborated on the study of a low-losses Faraday Isolator (FI) for the Einstein Telescope. This device is crucial in optics field, as it prevents back-reflection of the laser and minimizes losses in highly precise optical setups, such as those used for squeezing generation. Since for the squeezing measurements is crucial to have low losses, integrating this type of device is important and I am involved in the development of a new FI inspired by Advanced Virgo Plus (AdV+).

Specifically, I am studying materials for FI that are suitable for the 1550 nm wavelength required for the Einstein Telescope, as the materials currently used in AdV+ are not optimal for this wavelength. The requirements are losses less than 1% in a single pass and an extinction ratio of around 40 dB, similar to that of the AdV+. I have identified Yttrium Iron Garnet (YIG) as a promising crystal for its low-loss properties, making it a strong candidate for future isolator applications.

In the next phase of my work, I will focus on the implementation and validation of the local control system for the SIPS Fabry-Perot cavities. This includes performing in-depth testing and calibration of the double pendulum suspension system with monolithic fibers, to ensure the system effectively reduces thermal noise below the radiation pressure noise threshold. I will verify the transfer functions for each degree of freedom (pitch, yaw, and z-pendulum) by analyzing the response of the system to controlled disturbances in Rome. Next year, I also plan to test the low-losses Faraday Isolators at the EGO (European Gravitational Observatory) Virgo lab and in the Genova lab.

Course's/School/ Exam

I attended the following courses in my second year.

No.	Course/School	Status

i	Quantum Optics	Passed, July 2024
ii	Introduction to the Foundations of Quantum Mechanics and Applications	Passed, Oct 2024
iii	Microscopic and Spectroscopic Techniques for the Analysis of Surfaces and Interfaces	Exam will be shortly
iv	Gravitational Waves	Exam will be shortly
v	Sigrav International School - Measuring Gravity https://agenda.infn.it/event/38520/	Attended, 19-23 Feb, 2024

Conferences / Workshop

I attended a workshop in Rome, Italy, focused on Gravitational Waves, Electromagnetic, and Dark Matter Physics from September 16 to 19, 2024, where I presented a poster.
https://agenda.infn.it/event/39794/