Federico Armato

Tutor(s): Andrea Chincarini, Marco Raveri

Università degli Studi di Genova

E-mail: 4339821@studenti.unige.it

Research Activity

During my first year of PhD, I focused on the detection of gravitational waves and the **reduction of low-frequency noises** in gravitational-wave interferometers.

These are instruments with incredible sensitivity, which is an advantage and a challenge at the same time. On one hand, interferometers allow us to measure tiny gravitational wave signals, such as those generated by gravitational collapses of far binary systems. On the other hand, their sensitivity makes them extremally susceptible to any disturbances that can produce vibrations (e.g. thermal noise, seismic noise, quantum noise, gravity fluctuations).

Electrical and magnetic noise will be relevant in the low frequency band of third-generation interferometers and of future upgrades of current detectors. This is where my research project comes in.

Deposits of **charge** were found in the **test masses** (the interferometer mirrors) of both Virgo and LIGO detectors. This is a crucial issue, since the charge on the mirrors **interacts with the surrounding electrostatics**, generating unwanted noise. Moreover, the charging process is not yet completely understood, and its comprehension is challenged by the presence of vacuum.
Among the hypothesis that can explain the charging, the most accredited are the cosmic rays presence and the vacuum pumping process.
My PhD project deals with this problem. Indeed, it is possible to act on the charge by observing when and how it is deposited on the mirrors, thereby reducing this source of noise. Moreover, in this way we can gain more insights into the mechanism behind the charge deposition.

In order to develop an efficient **monitoring system**, I focused on the Information Optimization Theory. The region around the test mass is the most sensitive part of the interferometer, therefore the options for sensor placement are limited. It is then necessary to find the best configuration and the minimum number of sensors required to estimate the charge distribution on the mirrors. To accomplish this, I learned and exploited the **Principal Component Analysis (PCA)** technique, gained knowledge with **COMSOL Multiphysics** software and improved my skills with **MATLAB** software.

Given that **external magnetic fields** are also a significant source of noise at low frequencies, I worked on their reduction too. Specifically, I evaluated the effect of **passive shielding techniques** by exploiting induced currents and high permeability materials. Again, I mostly worked with COMSOL Multiphysics simulations and processed the data with MATLAB.

The preliminary results of these works have been resumed in two posters and in a conference presentation at the XIII ET Symposium held in May 2023.

The Charge Problem:

The first step of the charge monitoring work has been to simulate a toy model. The goal was to determine whether PCA could be a valid tool for sensor selection. I considered a simple mirror geometry (a cube) and a simple charge distribution (gaussian). Then, I simulated different configurations using COMSOL Multiphysics, varying position and standard deviation of the distribution. Later, I selected an arbitrary number of sensors and evaluated how well these sensors could describe different charge configurations by using clustering processes. Finally, using PCA, I selected the sensors that provided the largest amount of information and I observed that these sensors predicted the charge configurations with a precision comparable to that obtained using all the sensors. The conclusion was that **PCA** is indeed a **valid tool for sensor selection**.
The next step, which is my current work, involves repeating the same procedures for the real system.

The Magnetic Noise Problem:

Concerning the reduction of magnetic noise, I chose to use passive shielding techniques since they have the advantage of being simple, cheap and maintenance-free. The idea was to follow a twofold approach: shielding the system from external magnetic fields and, if possible, screening the noise sources themselves.

Regarding the first approach, I simulated the interferometer tower, where the mirror is located, using COMSOL Multiphysics. I tested how different shielding configurations responded to oscillating external magnetic fields at different frequencies. This allowed me to

estimate the **magnetic shielding factor** as a function of frequency and evaluate which configurations provide the best noise reduction factor.
Since we considered only the test mass, the future possible steps could be: quantitatively evaluate how much the different parts of the interferometer contribute to the magnetic noise (coupling coefficient map), establish which shielding factor is needed for each component, choose where and if integrate with active solutions.

Concerning the screening of noise sources, I simulated the simple case of a current-carrying wire, and I observed the effectiveness of an aluminum foil in shielding it.
A future action could be locate the main sources of magnetic noise and screen them.

Attended Courses

- **Gravitational Waves (6CFU)**
  Teacher(s): Andrea Chincarini, Gianluca Gemme, Fiodor Sorrentino
  Status: passed
- **Physics of Cosmic Structures (6CFU)**
  Teacher(s): Marco Raveri
  Status: not given yet

Conference Presentations

- **XIII ET Symposium**
  Passive magnetic shielding for test-mass towers — May 2023 - presentation
  https://indico.ego-gw.it/event/562/contributions/5010/
- **XIII ET Symposium**
  Mitigation of Low-Frequency Magnetic Fields — May 2023 - Poster
- **XIII ET Symposium**
  Charge Monitoring on Mirrors — May 2023 - Poster