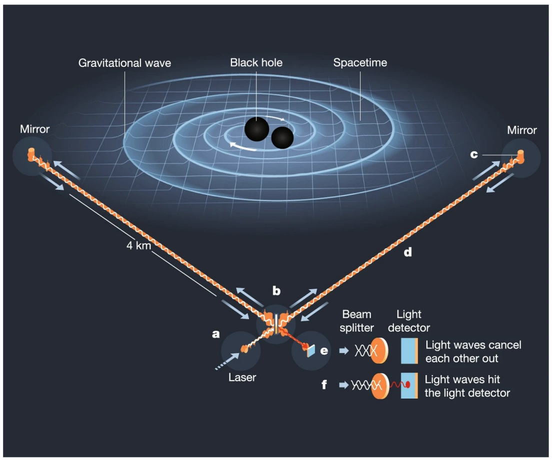
How to set up a Gravitational Wave Detector



SUMMARY.
Gravitational Wave Detectors are a powerful and unique tool to study the mysteries of our Universe. Unlike optical telescopes, they are able to directly detect merger between two black holes, black hole and neutron stars, among other sources. They work as Michelson interferometers which use lasers to convert small length changes caused by a gravitational wave to power changes which we can measure with a photodetector. Currently these detectors are able to measure length changes more than a thousand times smaller than the diameter of a proton. To achieve this incredible sensitivity they had to come up with complex designs and innovative techniques to overcome quantum noise, thermal noise, seismic noise, laser noise, among others. In this course you will learn the challenges of Gravitational Wave Detectors and will have the opportunity to set up a small Michelson interferometer and measure its sensitivity curve and the displacement of one of its mirrors. Hence, you will learn in theory and practice the basic experimental techniques to set up a Gravitational Wave Detector! The theory and experimental part of the course will be given at the Côte d'Azur Observatory (Mount Gros site), and you will interact with researchers that are active in the LIGO-Virgo-KAGRA collaboration, and work on the group which built the lasers for the Virgo detector.

OBJECTIVES

- Understand the theory of how a Gravitational Wave Detector works, and what are the noise sources that limit their sensitivity, especially laser noise
- Gain general knowledge of optics experimental techniques, interferometer alignment, control loops
- Learn how to measure the sensitivity of interferometers, and how to perform laser power stabilization

PREREQUISITES

- ✗ S1. Fourier Optics
- ✗ S1. Signal & Image processing
- ✗ S2. Gravitation & Cosmology
- ✗ S2. Quantum mechanics
- ✗ S2. Atmospheric turbulence, image formation & adaptive optics

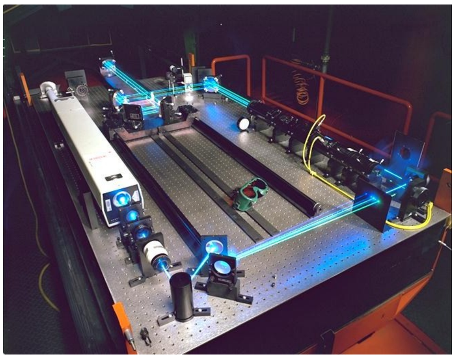
THEORY

by Margherita Turconi and Marina Nery

- Introduction to gravitational waves
- Basic principles and sensitivities of Gravitational Wave Detectors
- Noise sources in Gravitational Wave Detectors: quantum noise, thermal noise, seismic noise, laser noise
- Laser stabilization techniques
- Einstein Telescope and future plans for Gravitational Wave Detectors

APPLICATIONS

by Margherita Turconi and Marina Nery



Picture source: https://en.wikipedia.org/wiki/Optical_table

After an introduction to lab practice, students projects will include, for example, some of the following activities:

- Characterization of a laser beam
- Set up and align a Michelson interferometer
- Implement a control loop to stabilize and operate the interferometer at the mid fringe
- Measure the interferometer displacement sensitivity curve
- Identify and analyze noise sources
- Stabilize the power of the laser at the input of the interferometer

MAIN PROGRESSION STEPS

- Theory courses and exercises: 3 weeks
- Lab work and analysis: 4 weeks

EVALUATION

Theoretical part 30%: exercises that will be handed gradually during the theoretical course. Application part 30%: a full report of the experiment covering measurements and its analysis. Final defense 40%.

BIBLIOGRAPHY & RESOURCES

- https://www.ligo.caltech.edu/
- https://www.einsteintelescope-emr.eu/en/

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