# Introduction

In this curricular unit, we aim to discuss the inner workings, characteristics, and types of Sensors and their signals, approaching them in a scientific manner. In particular, we will focus on **Optical Sensors** and specifically **interferometric sensors** to understand the potential of one of the most high-performance tools in physics these days and reflect on the challenges of the field, from classical to quantum regimes.

**One of the major goals** of the course is to provide a critical perspective on these topics introducing key concepts while engaging in interactive discussions and hands-on activities to see the concepts at work. By focusing on the concepts, the aim is to provide the necessary tools and solid cornerstones for a student who wishes to explore the topic of optical sensors in more detail. **The second goal**, and more general, is to provide the students close contact with techniques, materials, and skills closer to scientific research, acting as additional building blocks for their future career.

## 1 Program

**A. Sensing and data analysis techniques and methods**
*Week 1*-What is a sensor and how to characterize one.
*Week 2 and 3*-Handling output signals: static and time-varying; frequency analysis; brief introduction to data visualization and machine learning for science.

**B. Classical Optical Interferometers for Measurement/Sensing**
*Week 4*-Why Light Excels in Sensing and what is an Interferometer. Interference as the building block of interferometric sensing. Newton's Rings and Double Slit experimental demonstrations.
*Week 5*-Interferometers: matrix formalism and overview of Michelson, Mach-Zenhde, and Sagnac Interferometers. Hands-on with a Michelson Interferometer and Mach-Zehnder.
*Week 6*-Fabry-Perot interferometer and outlook and perspectives of classical interferometeric sensing. Discussion of the past, present, and future of interferometers.
*Week 7*- Homodyne, Heterodyne detection: Pros and cons of heterodyne

detection for phase recovery in optical interferometers and characterization of their performance. A case study with pseudo-heterodyne detection in the context of optical fiber sensors.

**C. Semi-Classical Optical Interferometers for Measurement/Sensing**
*Week 8*- LIGO Case study - tackling the challenge of ultra-sensitivity. The role of noise and quantum fluctuations. The standard quantum limit.
*Week 9*- LIGO Case study with quantum formalism - Squeezed light: concepts and generation. Noise reduction below the standard quantum limit.

**D. Quantum Sensing with Optical Interferometry**
*Week 10*-Quantum light sources and detectors. Optical interferometers with entangled states and non-classical light sources. Quantum Metrology.

**E. Additional topics in Optical sensors**
*Week 11*-Other optical sensors: back-scattering and distributed acoustic sensing. Optical sensors exploiting resonant phenomena: surface plasmon resonance and whispering gallery modes. Spectroscopy: techniques and tools.

*Week 12*-Project tutorials and exercises.

## 2 Evaluation

The evaluation method includes a final exam. The students can choose to be assessed only based on the final exam, in which case the exam grade is the final grade, or presenting an optional written report can be considered for 40% of the grade. In this case, the final grade is computed as:

$$Grade = 0.6 \times Exam + 0.4 \times Report$$

**It is recommended that students choose the evaluation with a project component.**

## 3 Course Materials

**1. Lecture Notes**
Compilation of key ideas and contextual help for the activities. These should be utilized by the students to better prepare each week.

**2. Jupyter Notebooks**
To be utilized during the class to provide a hands-on approach to the topics of signal processing and analysis.

## 4 Recommended Bibliography

In addition to the **Lecture Notes**, which compile most of the relevant information for the curricular unit, students may utilize the following bibliographic references:


1. Robert D. Guenther; Modern optics. ISBN: 0-471-51288-5

2. Fraden, Jacob, and J. G. King. Handbook of modern sensors: physics, designs, and applications. Vol. 3. New York: Springer, 2010.

3. Reitze, David; Saulson, Peter; Grote, Hartmut (Editors); Advanced Interferometric Gravitational-wave Detectors: Essentials of Gravitational Wave Detectors. ISBN: 978-9813146075

4. Bachor, Hans-A.; Ralph, Timothy C.; A Guide to Experiments in Quantum Optics. ISBN: 978-3-527-41193-1

5. Max Born; Principles of optics. ISBN: 0-08-018018-3