UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Esperimentazioni di Astrofisica

2627-3-E3001Q058

Aims

The course learning outcomes include both fundamental knowledge of basic astrophysical concepts (Dublin Descriptor 1), the development of scientific research skills (Dublin Descriptor 2) and transversal skills (Dublin Descriptors 3, 4, 5). In particular, through this course, the students will learn:

1. Basic instrumentation and techniques for Astrophysical observations (Dublin Descriptor 1);
2. How to conduct observations of astronomical sources and signal calibration (Dublin Descriptors 1, 2);
3. How to perform data analysis and learn how to derive physical variables associated with astronomical sources (Dublin Descriptors 1, 2).
4. Writing scientific analysis codes in Python (Dublin Descriptor 2)

Regarding transversal skills (Dublin Descriptors 3, 4, 5), students will learn to:
i) ask and refine scientific questions, ii) identify relevant variables in physical problems , iii) propose testable hypotheses, iv) make assumptions, v) reduce complex problems into smaller units, vi) share and communicate results, and vii) write a scientific report.

Contents

The course is divided into two laboratory modules plus a series of lessons on Python programming, which are an integral part of the laboratory. The two laboratory modules will be preceded by introductory lessons to the laboratory activity.

- The first module concerns the analysis of photometric images in the optical band of spatially resolved galaxies obtained with the Telescopio Bicocca and public professional surveys.
- The second module concerns the spectroscopic observation and analysis of data acquired with the Radio Telescope in the 1.4 GHz band on galactic regions containing atomic hydrogen clouds.
- The programming module covers an introduction to Python and the use of Jupyter Notebooks for scientific

computing and data analysis.

Detailed program

The course is divided into two laboratory modules plus a series of lectures on Python programming.

The first part of the teaching will consist of a series of introductory lectures:
a. Python module: 12 hours on scientific computing and data analysis;
b. Optical telescope and Radio telescope modules: approximately 10-15 hours of introduction to the observations and laboratory activities.

Laboratory activities will be divided into two modules.

1. Optical Telescope Module;
2. Radio Telescope Module.

Students will work in groups; each group consisting of 3 students. Each group will work with both the Optical Telescope and the Radio Telescope. The total commitment is approximately 42 hours for each module. The two modules will be followed in parallel on different days of the week.

- **Programming module**:
  This introductory module aims to provide basic skills in using the Python language for the analysis of astronomical data. The goal is to equip students with the necessary tools to carry out laboratory activities and, more generally, applications in the scientific field that require data processing. During the module, the following topics will be covered, with examples and hands-on exercises:

- Basic Python programming for scientific computing: We will revise the use of fundamental libraries such as NumPy for numerical calculations, Matplotlib for creating figures, graphs, and animations, and Pandas for efficiently reading and managing tables.

- Statistical methods for the analysis of count data: Special attention will be given to the Poisson distribution and the estimation of uncertainties in counts, crucial elements in the analysis of astronomical data.

- Management and visualization of tabular astronomical data: We will work with data from real catalogs (CSV and TSV formats), with specific examples related to optical telescope and radio telescope modules. The developed codes will be useful for dealing with the optical telescope and radio telescope modules.

- Use of physical units and transformations between astronomical coordinate systems: We will explore the functionalities of the Astropy library for handling units and converting between different astronomical coordinate systems.

- Introduction to the FITS format (Flexible Image Transport System): We will learn techniques for reading, modifying, and writing FITS files, whether they contain images or tables.

- Basic techniques for astronomical image analysis: We will see how to apply methods such as image stacking to improve the signal-to-noise ratio, leveraging the concepts learned about uncertainty in a Poisson process applied to photon counting.

This module will be held at the beginning of the course, providing a solid foundation to successfully tackle subsequent lab activities and, more generally, other applications in the scientific field.

- **Optical Telescope Module**:

The learning outcomes of this module include both fundamental knowledge (Dublin Descriptors 1-2) and the development of basic and transver skills (Dublin Descriptors 3-5). In particular, through the usage of photometric data obtained with the Telescopio Bicocca and public surveys, the students will learn:

1. how to classify galaxy morphologies in terms of their light distribution profiles
2. how to relate galaxy morphological properties (size, light distribution profile) to the galaxy stellar properties (stellar mass, age, star formation rate) and to other possible components in order to infer the evolutionary paths for galaxy formation and their dynamical equilibrium.

Learning outcomes in terms of scientif skills and transverse skills (practice; Dublin descriptors 3-5), include:

- The students will learn how to combine the observational data and theoretical models to formulate meaningful questions and hypotheses galaxy formation, as well as strategies to test them.

- Through this course, the students will learn/consolidate the fundamental skills in scientific research practice including: i) asking and refining scientific questions, ii) finding relevant variables in physical problems, iii) making testable predictions, iv) making relevant assumptions, v) reducing complex problems in smaller units, vi) effectively sharing and communicating the results.

- **Radio telescope module**:

The learning outcomes of this module include both fundamental knowledge (Dublin Descriptors 1-2) and the development of basic and transver skills (Dublin Descriptors 3-5).
Each group will carry out observations of celestial sources, in the 1.4 GHz band, in particular of galactic regions containing atomic hydrogen clouds. The observations will be spectroscopic and will allow to recognize the emission of atomic hydrogen.
Each group will manage an observing program with the radio telescope and will analyze the collected data. The results will be described in a short report, which will be discussed at the exam.

Learning outcomes in terms of scientif skills and transverse skills (practice; Dublin descriptors 3-5), are addressed to learn to:

- Make observations with the telescope
- Analyze the acquired data
- Calibrate the signal with known sources
- Describe in a short report activity carried out and results

The specific scientific objectives could include the following topics:

- Study of the dynamics of the observed regions
- Study of the rotational speed of the disc

- **Introductory lessons**:
  Some of the astronomical sources to be observed and the astrophysical observables are described. The techniques and instrumentation used in laboratory observations are also introduced.

Prerequisites

Students are requested to know the content of courses of Physics and Laboratories followed in the previous years.

Teaching form

The teaching method will be mixed and will include both lessons carried out in frontal mode and exercises carried out in interactive mode.
Lessons will be held exclusively in person. For laboratory activities, including the Programming Module, presence is mandatory.

1) **Programming module**: Lessons of 2-3 hours carried out in presence mode;
2) **Laboratory modules**: 3-4-hour laboratory activities carried out in interactive mode in person; There is an introductory part in delivery mode which will cover the first weeks of activity. We recommend students to bring a laptop.

Textbook and teaching resource

1) Slides and notes of the introductory lectures, provided by the lecturers.

2) Software codes and packages for driving instruments and data analysis.

Semester

Second semester: approximatively from end of February till the beginning of June.

Assessment method

Final assessment with the usual score up to 30, including:

1) **Optical Telescope Module**: Presentation of the activity carried out and the results obtained; **Radio Telescope Module**: Written report describing the work carried out in the laboratory, including the measurements taken and the data analysis.

2) **Final oral exam**: related to the discussion of the presentation and report prepared by each group.

Within each group, in addition to the activity carried out, the student's maturity, mastery of the topics covered, clarity and propriety in language, and critical ability will be evaluated.

Office hours

On request to the various teachers.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE