UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Galaxy Evolution in Cosmic Structures B

2526-113R022

Aims

- Introduce practical application of "forward modeling" to compare state-of-the-art hydrodynamical simulations of galaxy formation with observations.
- Help students critically analyze comparisons between theory and observation and spot systematics.
- Provide hands-on experience in simulating observational effects like noise, blurring (PSF/LSF), and redshift-space distortions.
- Enable students to design their own "apples-to-apples" comparison pipelines for their research.
- Enable students to use numerical data from state-of-the-art cosmological simulations to gain valuable insight into astronomical observations.

Contents

This course aims to bridge the fundamental gap between 3D simulation data and messy 1D/2D observational data. Using simple examples, we will cover the principles of "forward modeling"—the art of simulating the observational process.

Key contents include:

- Understanding observational effects like noise, blurring (PSF/LSF), and redshift-space distortions.
- Hands-on Python implementation to create realistic mock galaxy images (comparing mass vs. light) and mock Lyman-alpha spectra (comparing density vs. flux).
- Learning to think about, analyze and design robust "apples-to-apples" comparisons between theory and observation.

Detailed program

The course, which is a follow-up of the course Galaxy Evolution in Cosmic Structures A, is divided into two large modules. Both will explore the forward-modeling of state-of-the-art cosmological simulations, with the spirit that students can generalize these ideas and apply these same techniques to new problems in their own research, whether they work with galaxy images, spectra, or other data types.

Module 1: The 2D Observational Pipeline & Mock Galaxy Photometry: We will learn to handle simulation data and establish the "ground truth". Our primary case study will be a simulated galaxy. We will cover the full pipeline to create a realistic mock observation, including:

1. Stellar Population Synthesis (SPS) to convert particle mass to light.
2. Point Spread Function (PSF) convolution to simulate optical/atmospheric blurring.
3. Adding realistic sky background and instrumental noise.

Hands-on Goal: We will create, "observe," and analyze a mock galaxy image, to then carry out in a direct comparison of the "true" 3D mass profile with the "observed" 2D light profile.

Module 2: 1D Spectral Data, Redshift-Space. This module tackles 1D spectra. We will be the Lyman-alpha forest, which reveals the intergalactic medium (IGM). We will explore a different set of observational systematics, including

1. The physics of Ly-alpha optical depth.
2. The critical effect of Redshift-Space Distortions (RSDs).
3. Simulating a spectrograph's Line Spread Function (LSF).
4. The continuum fitting.

Hands-on Goal: We will generate a mock quasar spectrum from a simulation skewer and discover how the final "observed" Flux PDF is fundamentally different from the "true" underlying density field.

The course concludes with a final synthesis lecture on the universal principles of forward modeling and a discussion on what we can (and cannot) learn from numerical simulations.

Prerequisites

- Graduate-level understanding of the basics of cosmology and galaxy formation.
- Proficiency in Python and standard scientific libraries.

Note: There is **no need** to have attended the course Galaxy Evolution in Cosmic Structures A.

Teaching form

The course will consist of electronic presentations covering the key concepts of each module, followed by hands-on exercises. It will consist of 16 hours split into two 3-hour lectures per week covering frontal lectures and hands-on excercises. Each module will be completed over the course of approximately one and a half week, with sufficient in-class time provided for students to finish the module's exercises within that week.

Textbook and teaching resource

1. The required material will be provided during the lessons, both as electronic presentations and shared files.
2. The simulation data and required software will be provided during the lectures.

Semester

The course will be offered during for the 2025/2026 academic year, starting in January.

Assessment method

The final assessment will consist of an oral exam and a written report summarising the findings of the proposed exercises.

Office hours

By appointment

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE