Master of Physics

Astrophysics Project Catalogue

2024-2025

Coordinator: Patrice Theulé

patrice.theule@univ-amu.fr

Faculté des Sciences
Aix-Marseille Université

Guidelines

- Students on the 'stars, galaxies and cosmology' track must perform 1 tutored project per attended lecture.
- For each lecture you can choose the project you want to perform (see list below). You will rank your choices and we will do our best to give you your first choice.
- M1 projects will take place during semester 2 and M2 projects during semester 3
- Projects grades will be assigned by a combination of supervisor assessment (1/2), oral presentation (1/2).
- Projects grades will count for 1/3 of the overall lecture grade
- Presentations will be of around 10 minutes duration and will take place before the end of the exam rehearsal week for the respective semester

M1 Projects

UE Stars & exoplanets

- M1PR01: Characterization of young stars and their disks (D. Russeil)

UE Cosmology

- M1PR02: Galaxy clusters’ number counts in X-ray: effects of dark energy (C. Schimd)

M2 Projects

UE Galaxies & Cosmology

- M2PR01 Cosmic Microwave Background fluctuations: from *Planck* maps to cosmological parameters (G. Lagache)

or

- M2PR02 Modelling of gravitational lensing systems (E. Jullo)

UE Stars & Galaxies

- M2PR03 Globular clusters : a Travel in Space an Time (D. Burgarella)

or

- M2PR04 New insights on the first galaxies from the *James Webb Space Telescope* (N. Laporte)

M1PR01: Characterization of young stars and their disks

Supervisor: Delphine Russeil, delphine.russeil@lam.fr

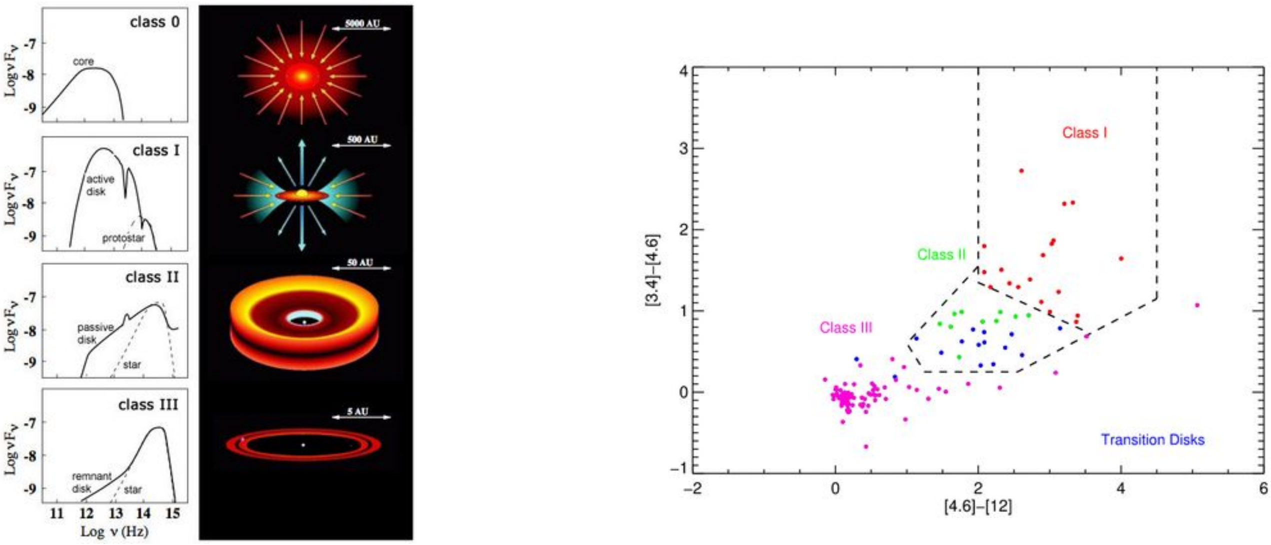


Figure: Left: Typical low mass YSO evolution scheme. Right: Example of a Color-color diagram used to select YSOs (Kang et al. 2017)

The first aim of this project is to characterise the pre-main sequence stars. These young stars are still surrounded by a disc of gas and dust from which planets form. The evolution of a YSO is classified into four subsequent phases, which correlate with the changes of its spectral energy distribution (SED).
The student will identify YSOs based on color-color diagrams and look at their spatial distribution.

The second aim is to perform a basic modelling of a circumstellar disc in order to e.g. understand their SED.
Coding by Python, C, or any other languages or tools.

Plan:

1. Sources extraction from dedicated catalogues and regions.
2. *Build the color-color diagrams and select YSOs applying the dedicated criteria.*
3. Plot their spatial distribution.
4. Basic disc modelling and visualistion.
5. Basic SED construction.

M1PR02: Galaxy clusters' number counts in X-ray: effects of dark energy

Supervisor: Carlo Schimd, carlo.schimd@lam.fr

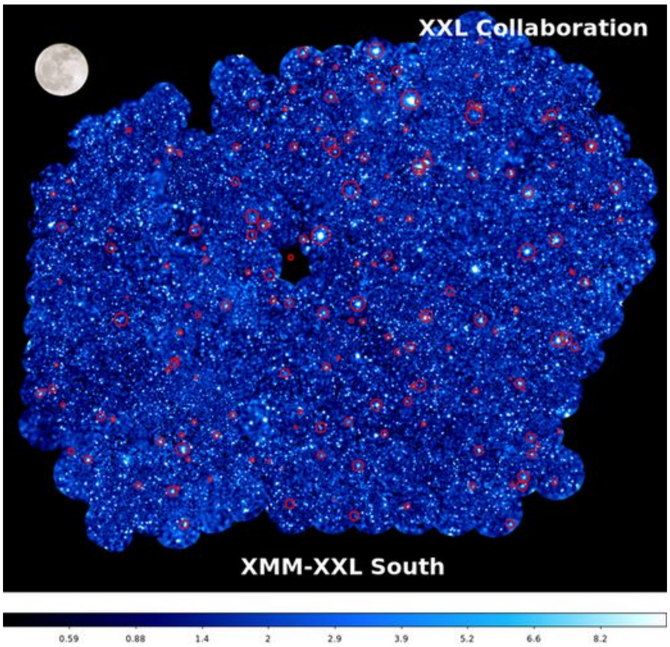


Figure: Southern field of the *XXL* survey, it covers about 25 deg^2 and show the X-ray flux of about 5×10^{-15} erg cm^{-2} s^{-1} in the [0.5-2] keV band. Red circles show the galaxy clusters, smaller signal comes from Active Galactic Nuclei (credit: ESA/XMM-Newton/XXL survey consortium).

The aim of this project is to handle the basics of cosmology by exploring one of the earliest, simplest, and still more powerful probes of cosmology: the abundance of galaxy clusters as detected by X-ray surveys. Being the more massive and virialized objects in the universe, the clusters of galaxies embed a large fraction of very hot gas emitting photons by Bremsstrahlung. Past-decade surveys operated by *Chandra* and *XMM-Newton* satellites and the ongoing survey operated by *eRosita* are designed to successfully detect this very tiny signal (see figure).

The student will compute the number count of clusters per comoving volume expected for a survey characterized by a flux limit and covered area, comparing the in the concordance LCDM cosmology and in alternative cosmologies with dark energy. This computation holds notions of homogeneous and inhomogeneous cosmology. Coding by Python, C, or any other language.

Plan:

6. Compute the cosmological distances and volume from (tabulated or analytic) Hubble parameter in several cosmology.
7. Deduce the flux f_X and determine the mass and redshift range observable for the *XXL Survey*.
8. For given linear matter power spectrum and growth factor, depending on the dark-energy model, deduce the mass variance $\sigma(M,z)$ and the non-linear mass scale $M_{\rm nl}(z)$.
9. For a given halo mass function, estimate the differential and total number counts of haloes with flux $f_X > f_{\rm lim}$ and their errors for different dark-energy models.

M2 Projects

UE Galaxies & Cosmology

- M2PR01 Cosmic Microwave Background fluctuations: from *Planck* maps to cosmological parameters (G. Lagache)

or

- M2PR02 Modelling of gravitational lensing systems (E. Jullo)

UE Stars & Galaxies

- M2PR03 Globular clusters : a Travel in Space an Time (D. Burgarella)

or

- M2PR04 New insights on the first galaxies (N. Laporte)

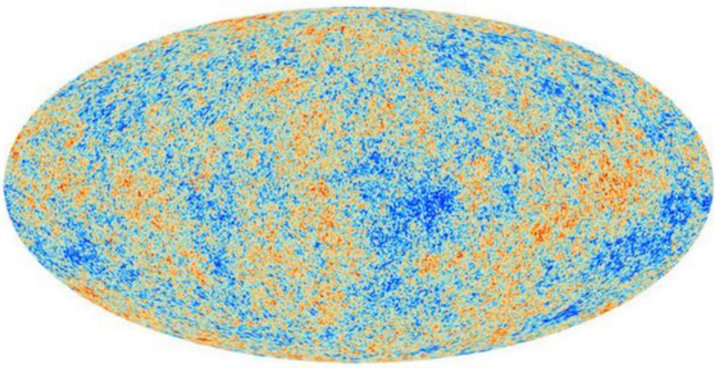
UE Planetary systems

- M2PR05 Planets beyond our Solar system (S. Sulis)

M2PR01: Cosmic Microwave Background fluctuations: from *Planck* maps to cosmological parameters

Supervisor: Guilaine LAGACHE, guilaine.lagache@lam.fr

The cosmic microwave background (CMB) is the thermal radiation left over from the time of recombination in Big Bang cosmology. It is a snapshot of the oldest light in our Universe, imprinted on the sky when the Universe was just 380,000 years old. It shows tiny temperature fluctuations that correspond to regions of slightly different densities, representing the seeds of all future structures. Precise measurements of CMB fluctuations are critical to cosmology, as any proposed model of the Universe must explain this radiation. This was the goal of the *Planck* space mission, designed to observe the CMB fluctuations with the highest sensitivity.



Cosmic Microwave Background fluctuations (credit: ESA and Planck collaboration)

The project is dedicated to the study of CMB fluctuations. First, CMB will have to be extracted from the *Planck* frequency maps. Indeed, the maps measured by *Planck* not only contain the CMB but also astrophysical foreground components, as dust emission from our Galaxy. Second, the CMB power spectrum will be computed, and compared to the *Planck* best-fit cosmological model. Finally, the measurement of the power spectrum will be used to constrain some cosmological parameters.

Work plan :

Session 1: (10% of time)

- Brief presentation/understanding of the physics of CMB fluctuations.
- First hands on *Planck* maps: Healpix representation, units.

Session 2: Component separation: extracting CMB from *Planck* maps (45% of time)

- Form the internal-linear-combination map from a weighted linear combination of the *Planck* maps in which the weights are chosen to maintain the CMB fluctuations signal while minimizing the Galactic foreground contribution.
- Assess the quality of the CMB fluctuations map, build masks for problematic regions.

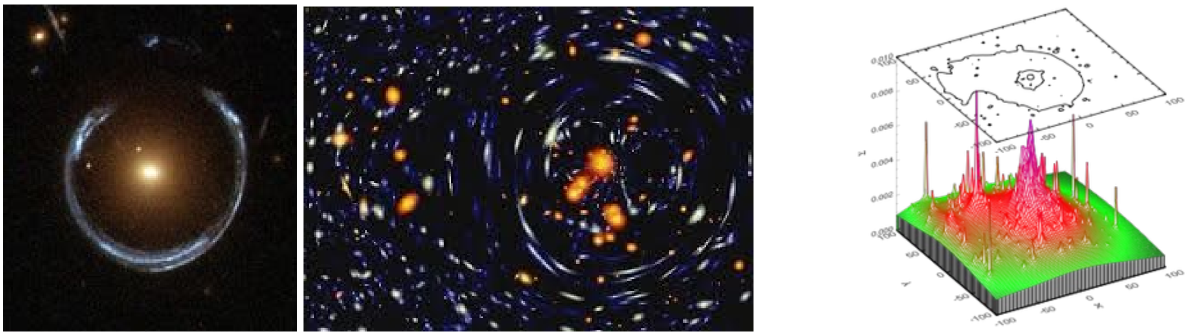
Session 3: CMB Power spectrum and cosmological parameters (45% of time)

- Compute the power spectrum of CMB fluctuations on the previously derived CMB map.
- Understand and remove the instrument noise contribution, and "debias" the CMB power spectrum from the point spread function.
- Compare with Planck best-fit cosmological model.
- Compute some cosmological parameters.

M2PR02: Modelling of gravitational lensing systems

Supervisor: Eric jullo eric.jullo@lam.fr

The project aims at studying gravitationally lensed systems of different kinds, from galaxy to galaxy-cluster scale systems. Throughout this project, the students will learn the theoretical basics of gravitational lensing, the observational challenges and the different modelling approaches that have been developed so far. They will discover the potential of this technique at characterizing dark-matter and dark-energy properties. They will learn how to simulate a strong lensing effect, and how to infer the mass from lensing observations.



Left: Horseshoe Einstein ring. Middle: Simulated lensing effect. Right: Mass map of galaxy-cluster Abell 1689 reconstructed from lensing observations

The work plan of the project is as follows:

- Introduction from general relativity metric to the lens equations. Lensing calculations in Python
- Observations in the strong and weak-lensing regimes. Mass estimate from an Einstein ring observation in Python
- Simulating a lensing effect in Python

References:

Kneib & Natarajan, 2011 “ Cluster Lenses”, https://arxiv.org/abs/1202.0185

M2PR03 : Globular clusters : a Travel in Space an Time

Supervisor: Denis BURGARELLA, denis.burgarella@lam.fr

The main objective of this project is to simulate the time evolution of the stars in a globular cluster. We will monitor this evolution on the theoretical Hertzprung-Russel diagram (HRD) and on a color-magnitude diagram (CMD) to simulate what an observer would see from various positions in time and space. The Python programming language will be used and more specifically Matplotlib animations.

This project is divided into successive steps building up on the previous ones. The final objective is to simulate a stellar population from a globular cluster, whose distribution of stars follows a given distribution in 2D and 3D, and to plot these stars in a HRD (Figure 1). If time allows, you will develop an interface to move around at various distances and speeds from this globular cluster (assuming the time is frozen).

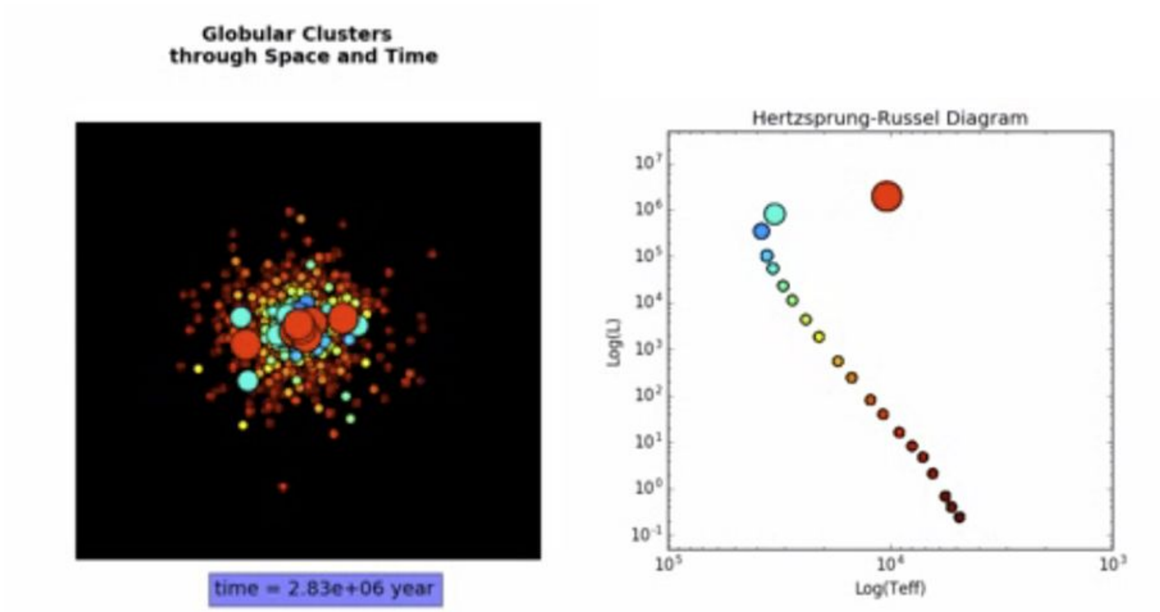


Fig. 1: Examples of visualization of the globular cluster in 3D (left) and the corresponding HR diagram (right). Note that both evolve intime, color and size.

The steps of the project are:

- Simulate the distribution of stars in a globular cluster
- Build an animation of the evolution
- Simulate the evolution of stars in a HRD and in the CMD
- Change the position of the observer
- Move the position of the observer as in a journey. You can have an idea of what can be done (assuming a given position in space and time) from this animation:

https://www.dropbox.com/s/w4bw24lezoebrlp/Glob_Evol_10000_v2.mp4?dl=0

M2PR04 : **Glo**M1PR01: New insights on the first galaxies from the *James Webb Space Telescope*

Supervisor: Nicolas Laporte, nicolas.laporte@lam.fr

After its successful launch in December 2022, the *James Webb Space Telescope* (JWST) is now providing unprecedented, deep, and highly detailed images of our Universe. This capability allows for the characterization of the atmospheres of nearby exoplanets and the determination of physical properties of the most distant galaxies. Despite intense competition, the *Space Telescope Science Institute* (STScI) has promptly decided to publicly release a significant portion of the data acquired by this remarkable telescope.

In this context, STScI has released the deepest images and catalogs for one of the most well-known regions of the sky—the southern part of the *Great Observatories Origins Deep Survey* (GOODS-South). This project invites you to utilize JWST data obtained in 2023 for this field, enabling the study of the first populations of galaxies in the Universe. The primary objective of this project is to determine how the luminosity distribution of galaxies evolved within the first billion years of the Universe and showcase the impact of JWST on our understanding of the early Universe. You will develop several Python scripts in a *Jupyter Notebook* to read the JWST catalog, select galaxies within the first billion years, and extract the required information.

The theoretical component of this project will provide you with the foundational knowledge to understand galaxy formation and evolution, especially within the framework of hierarchical models in a cosmological context. It will also equip you with the latest insights into the study of distant galaxies before the advent of JWST. The initial five minutes of each lecture will be dedicated to a recent discovery in extragalactic astronomy made by the JWST in the past weeks.

Figure 1: The deepest image so far of our Universe obtained by the JWST in 2023. Credit: NASA, ESA, CSA, B. Robertson (UC Santa Cruz), B. Johnson (Center for Astrophysics, Harvard & Smithsonian), S. Tacchella (University of Cambridge, M. Rieke (Univ. of Arizona)

M2PR05: Planets beyond our Solar system

Supervisor: Sophia Sulis, sophia.sulis@lam.fr

The goal of this project is to discover what extrasolar planets are, how they are detected, and how their parameters are recovered. To do this, students will exploit photometric observations from NASA's Kepler and/or TESS satellites, which aims to detect extrasolar planets using the transit technique. Students will learn the basics of the transit technique, develop their own detection procedure, and explore in detail the limitations of this technique. They will also compare the properties of different type of exoplanets with those of the planets in our solar system.

The work plan for the project is as follows:

1) Introduction (10% of time).
- Extrasolar planets.
- Transit equations.
- First practical work on transit modeling (Python).

2) Analysis of Kepler/TESS space data (30% of the time)
- Photometric observations with Kepler/TESS satellites.
- First hand on the estimation of exoplanet parameters (Python).
- Comparison with the planets of the solar system.

3) Detection of extrasolar planets (60% of the time)
- Key concepts about detection theory.
- Implementation of a transit detection algorithm (Python).
- Evaluation of the performances of the algorithm