Thesis subject

Laboratory : Laboratoire d'Astrophysique de Marseille

Thesis supervisor : Olivier ILBERT

Co-supervisor : Léo MICHEL-DANSAC

Title of the thesis subject : Link the morphological evolution of galaxies and star-formation activity around cosmic noon.

Description of the thesis subject :

Cosmic noon refers to the epoch at redshifts $1 < z < 4$, a pivotal period in the Universe's history when galaxies underwent rapid evolution. During this era, star formation activity peaked (Madau & Dickinson 2013), while the massive galaxies—reaching up to hundreds of billions of solar masses—suddenly halted their star formation (Ilbert+13, Shuntov+25b). Simultaneously, galaxies experienced a dramatic morphological transformation, transitioning from disturbed, irregular structures to the orderly forms described by the Hubble sequence (Huertas-Compagny+25). The epoch $1<z<4$ is critical for unraveling the connection between morphological changes and star-formation activity. Over the past three years, the James Webb Space Telescope (JWST) has revolutionized our understanding of this period. By imaging galaxies in the near-infrared with unprecedented resolution and sensitivity, JWST enables us to characterize star-formation activity at $1<z<4$ with extraordinary precision.

The physical mechanisms driving these transformations are highly complex. Galaxy mergers act as a fundamental engine, reshaping morphology while simultaneously triggering bursts of star formation. Another critical—but still poorly understood—mechanism involves the energy released by the accretion disks surrounding supermassive black holes, where mergers may also play a significant role (Hopkins 2009). Such feedback efficiency is also related to other forms of feedback generated by supernovae and cosmic rays (Rosdahl et al. 2015, Lewis et al in prep). Meanwhile, dynamical evolution in gas-rich environments can lead galaxies to stabilize and develop a central bulge (Bournaud 2011). Despite their importance, these physical processes remain poorly constrained, and the relative contribution of each mechanism is hotly debated. Hydrodynamical simulations are essential for piecing together this puzzle, as they allow us to model the interplay between these processes. However, simulations must be validated against observational data to provide meaningful insights into the underlying physics.

This thesis aims to bridge observations and theory by combining cutting-edge JWST observations with high-resolution zoom-in hydrodynamical simulations to constrain the physical parameters governing galaxy evolution at cosmic noon. The study will draw on a rich, multi-wavelength dataset from the COSMOS field (https://cosmos.astro.caltech.edu/), integrating JWST observations from COSMOS-Web (Casey et al. 2025) and COSMOS-3D, alongside new HST data from the CLUTCH survey (Kartaltepe, HST Proposal. Cycle 33, ID. #17998). In parallel, the student will analyze zoom-in simulations produced using RAMSES (Teyssier 2002) and post-processed with RASCAS (Michel-Dansac et al. 2020), generating synthetic observations that mirror the real dataset. By synergistically combining these state-of-the-art observational and simulation tools, this work seeks to unravel the key physical mechanisms driving galaxy evolution during this pivotal epoch—with a particular focus on the interplay between morphological transformation and quenching.

We propose the following work plan for the PhD:

First Year: Data and Simulation Preparation

1. **Compilation of Observational Data** The student will compile the most up-to-date JWST and HST data for the COSMOS field. They will begin with an extensive dataset already assembled (available at cosmos2025.iap.fr, Shuntov+25a) and focus on integrating NIRCam JWST data with the new CLUTCH data, which will be nearly fully acquired and reduced by the start of the PhD. The student will contribute to incorporating HST data into the existing catalog, with guidance from an experienced team.

2. **Selection of Galaxy Sample** The student will select a sample of galaxies at cosmic noon with well-characterized physical properties, using template-fitting tools such as LePHARE (https://github.com/lephare-photoz/lephare) or CIGALE (https://cigale.lam.fr/).

3. **Simulation Pipeline Development** The student will learn to run RASCAS on existing RAMSES simulations, collaborating with team members experienced in RAMSES. They will enhance the capabilities of RASCAS, as needed (e.g., to include AGN and emission line modeling). The student will become the team's expert in running an observational pipeline that generates mock observations from zoom-in galaxy simulations and analyzes them using the same tools applied to the real dataset (e.g., SE+, LePHARE, CIGALE). During this first year, the student will integrate the CLUTCH data into the pipeline and develop the ability to model the AGN component, extracting information

such as the AGN contribution using the team’s analytical tools.

Second Year: Comparison Between Observations and Simulations, Initial Scientific Analysis

1. **Development of a Statistical Comparison Tool** The student will develop a novel statistical tool to compare high-resolution, multi-band images from HST and JWST with the outputs of the simulation pipeline. This tool will require the development of quantities measured on 2D images generated with simulations and observations. Standard fitting algorithm as well as simple machine-learning method could be envisioned.

2. **Analysis of Morphological Transformation** Using the results of this comparison, the student will be able to assess if our current description of the physical processes in current simulation can explain the observed morphological transformations as well as star-formation activity at cosmic noon. It will also allow to identify failures in the models. The goal is to publish a first paper on this comparative analysis.

Third Year: In-Depth Scientific Analysis of the Quenching Process

1. **Focus on Galaxy Transformation** By the third year, an advanced tool for combining observed and simulated galaxies at cosmic noon is expected to be developed and published. The student will focus on one of the most critical transformations occurring in galaxies during this epoch: the transition from disturbed, star-forming disks to quenched, elliptical galaxies. This topic is fundamental to understanding galaxy evolution.

2. **Investigation of Key Physical Processes** The comparison between observations and simulations will be central to this analysis. While AGN feedback and mergers are expected to play a crucial role, the student’s findings may highlight other processes. The student will collaborate closely with experts capable of integrating new physical processes into the simulations.

3. **Publication and Thesis Writing** The aim is to publish a fundamental paper linking morphological transformation to quenching, with a deep understanding of the underlying physical mechanisms. The student will also write its PhD manuscript.

The team

This thesis will be conducted at LAM (Laboratoire d'Astrophysique de Marseille), one of the leading institutes in galaxy evolution research, hosting one of the largest teams of experts in the field. The PhD advisor brings extensive experience in analyzing COSMOS and JWST data, with a particular focus on quenching processes at cosmic noon. The co-advisor is a recognized specialist in galaxy simulations, and is the developer of the RASCAS code, a key tool for this project. The thesis will benefit from close collaborations with researchers at IAP (Institut d'Astrophysique de Paris) and CEA (Commissariat à l'Énergie Atomique), who generate the zoom-in simulations using RAMSES. On the observational front, the student will join a large, international team actively compiling and analyzing JWST and CLUTCH data for the COSMOS field. Regular interactions with this group will ensure a dynamic and enriching research environment.

References :

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