ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DIPARTIMENTO DI FISICA E ASTRONOMIA
Department of Physics and Astronomy - DIFA

Borsa di Ricerca – Piano Formativo

Title of the Project: Image simulations of lensed systems: completeness and blending effects in highly magnified stellar clumps

Durata: 5 mesi

Supervisor: Lauro Moscardini

Piano Formativo:

The angular resolution of the James Webb Space Telescope (JWST) together with the magnification effect of strong gravitational lensing provide a real opportunity to study compact star-forming regions in the high-redshift Universe at physical scales that would otherwise be inaccessible. When considering the aid of gravitational lensing, JWST can probe clumps down to <10 pc in size and 10^5 M_{sun} in mass, reaching the scales of individual star clusters. One of the most important examples is the Cosmic Gems in the cluster SPT-CL J0615–5746 (Adamo et al. 2024, Messa et al. 2026, Vanzella et al. 2026), a strongly lensed galaxy at z=9.625, where JWST observations allowed the detection of five very dense (~$10^{5\text{-}6}$ M_{sun} pc^{-2}) and massive (~[1-6] x 10^6 M_{sun}) star clusters. These discoveries demonstrate that strong gravitational lensing has become an essential tool for investigating star formation at parsec scales in the high-redshift Universe. Despite these observational capabilities, the physical characterization of compact star clumps remains problematic. The finite angular resolution of JWST gives rise to crowding and blending effects and makes the study of the completeness particularly challenging. As a result, these effects limit the recovery of stellar masses, sizes, luminosities and ages, and our ability to investigate the evolution of stellar clumps' properties with redshift and their connection with the properties of their host galaxies (Claeyssens et al. 2025).

The main goal of this project is to quantify the impact of observational biases on the detection and physical characterization of stellar clumps in the Cosmic Gems (see Fig. 1). In particular, the project aims at studying the effects of crowding, blending and detection completeness on the recovery of the physical properties of stellar clumps, and to investigate how these effects depend on the lensing magnification by comparing highly magnified systems, such as the Cosmic Gems, with less magnified galaxies, such as the Cosmic Archipelago in the cluster MACSJ0416.

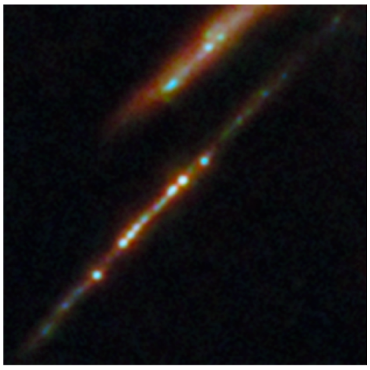

Figure 1: JWST observation of the Cosmic Gems Arc in SPT-CL J0615–5746 galaxy cluster in the NIRCam filter F150W.

The project will rely on *clumPyLen***,** a private simulation pipeline which generates synthetic clumpy galaxies, includes gravitational ray-tracing, and produces realistic JWST observations including instrumental PSF convolution and observational noise. The first part of the project will focus on reproducing the observed morphology of the Cosmic Gems, including the addition of five clumps with the same physical properties derived in Messa et al. 2026. The physical properties of all the simulated clumps will then be recovered following the method described in Adamo et al. 2024. In particular, clump fluxes and effective radii will be measured through a two-dimensional Gaussian profile fitting, while stellar masses and ages will be derived through SED fitting using the *Bagpipes* software (Carnall et al. 2018).

The project will then investigate source blending and detection completeness. Regarding blending effects, an analysis will be performed using ~100 simulated Cosmic Gems realizations. The five stellar clusters identified in the observed Cosmic Gems will be kept fixed, while the remaining clump population will be simulated in each realization with different sets of masses, effective radii, ages and spatial positions from the adopted input distributions. For every realization, the number of neighboring clumps within a circular aperture around the five target clusters will be measured, hence providing a statistical estimate of the blending probability for each cluster. Completeness simulations will instead explore the detectability of stellar clumps over a wide range of intrinsic masses, sizes and ages under different Signal-to-Noise ratio conditions, producing completeness functions as a function of local noise.

Finally, the same simulation analysis will be applied to less magnified lensed systems, such as the Cosmic Archipelago, to quantify how decreasing magnification affects clumps detectability, blending, completeness and the accuracy of the recovery of stellar clumps physical properties.

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