Thesis subject

Laboratory : Laboratoire d'Astrophysique de Marseille

Thesis supervisor: Nicolas Laporte

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Title of the thesis subject: Unveiling the properties of the first proto-clusters formed in the Universe using Euclid

Description of the thesis subject: A key goal of modern extragalactic astronomy is undoubtedly to understand how the first stars and galaxies began to bathe the Universe in light. Over the last two decades, this topic has reached a golden era, due to the arrival of 8-10m class ground-based telescopes (e.g., the Very Large Telescope, Keck Observatory, Gran Telescopio Canarias), and the recent launch of large near-infrared space observatories (such as the *James Webb* Space Telescope and *Euclid*), pushing ever further the boundaries of the observable Universe. This quest for the first light in the early Universe led to the detection of hundred of primeval galaxies (e.g., Bouwens et al. 2015, Donnan et al. 2023) observed a few hundred million years after the Big-Bang (in terms of redshift, $z>6$), that is through the period of reionization of the Universe, not yet fully transparent to photons.

When the first stars and galaxies start to illuminate the Universe, they begin to ionize the neutral hydrogen that has been formed after the Big-Bang. According to the Planck results (Planck 2016) and quasars observations (e.g., Bosman et al. 2022), the reionization process ends one billion years after the Big-Bang, the so-called epoch of reionization (EoR). This period is a boon to understanding the physical properties of primeval ionizing sources: they must have emitted enough ionizing photons within the first billion years of the Universe. However, when estimating the contribution to the reionisation thanks to the observed high-redshift galaxy populations, there is a clear deficit of ionizing photons. Therefore either primeval galaxies have different ionizing properties than low-redshift galaxies or additional ionizing sources must be considered, or the model for the efficiency to form stars at high redshift must be revised. Even after more than two years of JWST operations, there is not yet a clear answer to this hot debate.

While the formation timeline of primeval galaxies is starting to be unveiled by the deepest JWST observations, details about its spatial extent remain unclear: were galaxies formed in isolation or in groups? According to lensed and blank field observations, the most massive galaxies appear to be surrounded by fainter galaxies in small protoclusters (e.g., Laporte et al. 2022, Castellano et al. 2023, Tacchella et al. 2023). Numerical simulations suggest that the physical properties of galaxies (such as metallicity, star formation rate, dust content) within these first protoclusters should evolve differently depending on their position within the structures (Bennett & Sijacki 2024). More interestingly, the spatial extent of these early structures could give new constraints on the dark matter halos properties a few hundred million years after the Big-Bang. Simulations also predict that Active Galactic Nuclei (AGN) may be located at the center of these protoclusters at high-redshift. Therefore identifying and characterizing these first structures in the early Universe is key to understanding the galaxy formation process.

The main goal of this thesis will be to identify proto-clusters at z>5 in the largest *EUCLD* images, to estimate their physical properties (with SED-fitting), to determine the nature of the brightest source in the proto-cluster core (galaxies hosting an AGN vs star-forming galaxies) and to conduct spectroscopic follow-up with the largest ground based-telescopes.

Timeline of the thesis: During the first year (Sept. 2025–Aug. 2026), the PhD candidate will develop a new tool, using Voronoi tessellation adapted to high-redshift sources, to identify over-dense regions at z > 5. This tool will be first tested on the largest fields observed with JWST (PRIMER -1837; PI: Dunlop). The second year (Sept. 2026–Aug. 2027) will be divided into two parts: (i) identifying protoclusters in the deepest surveys of *Euclid* and (ii) conducting a spectroscopic follow-up campaign using PFS/Subaru and MOONS/VLT as part of the GTO. The final year of the PhD (Sept. 2027–Aug. 2028) will focus on comparing observational results (photometry and spectroscopy) with simulations. Throughout the thesis, the PhD candidate will attend workshops, conferences and schools.

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