From JWST to ELTs: Revealing the Structure and Evolution of High-Redshift Galaxy Protoclusters

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The current paradigm of galaxy formation suggests that the first galaxies likely emerged within large dark matter haloes. The fragmentation of these massive haloes led to the formation of galaxy protoclusters, which typically consist of one or a few bright galaxies surrounded by numerous fainter, less massive objects. These early structures may have played a significant role in the reionization of neutral hydrogen during the first billion years of the Universe, especially if their number density was high. Thanks to the unprecedented sensitivity of the James Webb Space Telescope (JWST), galaxy protoclusters are now being detected at redshifts as high as $z = 10.6$. However, obtaining comprehensive spectroscopic follow-up across a broader field of view than the JWST can offer remains a challenge beyond the capabilities of current 8-10m class telescopes. The advent of the first Extremely Large Telescopes (ELTs) in the next decade will revolutionize our understanding of these primordial structures, enabling confirmation of their nature, probing metal distributions within protoclusters, and investigating the properties of the brightest galaxies in the protocluster cores, as well as their spatial extent. In this talk, I will present an overview of protoclusters at $z > 7$ (up to $z \sim 11$) identified in JWST data, along with recent spectroscopic follow-up observations using ground-based telescopes (e.g., VLT and Keck) and JWST. Additionally, I will share preliminary results on the distribution of galaxies from the first deep JWST surveys. Finally, I will highlight a use case study involving the new MOSAIC/ELT architecture, focused on one of the protoclusters identified by JWST.