M2 Internship Project

Dynamics of baryons in non-standard cosmological scenarios

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Most of the universe is made of invisible components whose nature remains unknown. Only 5% consists of standard model matter (baryons) which compose stars, planets and gas across cosmic scales. About 30% of the cosmic energy density is in a form dubbed dark matter (DM), an unseen specie that interacts through gravity only and drives the formation of cosmic structures, while about 65% consists of dark energy (DE), which is responsible for the accelerated expansion of the universe. The standard cosmological model (ΛCDM) assumes that DM is in the form of cold, collisionless particles, while a cosmological constant in Einstein's equation of General Relativity (GR) can account for DE. Although this scenario successfully reproduces a wide range of observations, the physical origin of these dark components is still unknown.

In particular, the small but puzzling value of the cosmological constant and the lack of detection of DM particles in laboratories have prompted the development of alternative scenarios. In the context of DE, dynamical models, where DE evolves over time resulting from the dynamics of a scalar field (as in the quintessence framework), as well as modification of GR on cosmic scales have been widely studied. Recent observational tensions, such as discrepancies in the Hubble constant and evidence suggesting a time-varying DE, have further strengthened interest in these models. In addition, observations of the high-redshift universe from JWST have revealed larger abundances of massive galaxies than expected in ΛCDM, although there is still no consensus on the origin of such a discrepancy.

In light of these results, it is timely to investigate the dynamics of baryonic matter in the late universe and the processes that lead to the formation and evolution of galaxies in alternative cosmological scenarios. In fact, the bulk of galaxy formation studies have been conducted within the standard ΛCDM framework. <u>A key tool for this investigation is the construction of halo merger trees, which describe the hierarchical assembly of dark matter halos hosting galaxies. During this internship, the student will first review the existing literature on merger tree models and algorithms. They will then study how non-standard DE models affect the statistical properties of merger trees, in particular the halo mass accretion rate, using semi-analytical approaches based on the Excursion Set Theory. The latter provides a stochastic model description of the halo formation and assembly process</u>. Depending on progress, the project may be extended to the analysis of merger trees extracted from cosmological N-body simulations and the setup of initial conditions for zoom-in hydro simulations of galaxies. This work serves as preparation for a potential PhD project on the impact of dynamical dark energy on the formation of galaxies in the universe.

Basic Knowledge & Skills: Cosmology (master courses on GR and Cosmology); coding in Python and/or F90 and/or C
Methodology: Analytical Modeling, Numerical Simulations, Monte Carlo Methods
Duration: 3 months
Location: Observatoire de Paris – Campus de Meudon