Joint simulation-based inference of thermal SZ maps and *Euclid*'s weak lensing

PhD position

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Application Deadline: 23/03/2026

Context

The *Euclid* mission will provide weak lensing measurements with unprecedented precision, which have the potential to revolutionise our understanding of the Universe. However, as the statistical uncertainties decrease, controlling systematic effects becomes even more crucial. Among these, baryonic feedback, which redistributes gas within galaxies and clusters, remains one of the key astrophysical systematic effects limiting *Euclid*'s ability to constrain the equation of state of dark energy. Understanding baryonic feedback is one of the urgent challenges of cosmology today.

The thermal Sunyaev-Zel'dovich (tSZ) effect provides a unique window into the baryonic component of the Universe. This effect arises from the scattering of cosmic microwave background (CMB) photons by hot electrons in galaxy groups and clusters. This is the same hot gas that has been redistributed by baryonic feedback and is particularly relevant for weak lensing. The cross-correlation of tSZ and weak lensing (WL) probes how baryons modify the cosmic structures, allowing us to constrain cosmology and baryonic physics.

Most current tSZ-WL analyses rely on fitting angular power spectra under the assumption of a Gaussian likelihood. However, the tSZ signal is highly non-Gaussian, as it traces the massive structures of the Universe, and the power spectra fail to fully capture the information in the data. To unlock the scientific potential of the tSZ-WL analyses, it is essential to move beyond these simplifying assumptions.

PhD thesis

The goal of this PhD project is to develop a novel simulation-based framework to jointly analyse tSZ and *Euclid*'s WL data. This framework will combine physically motivated forward models with advanced statistical and machine-learning techniques. The project will contribute to increase the accuracy of *Euclid*'s analyses and improve our understanding of the dark matter-baryon connection.

Outline of the project and methodology

1. Develop a forward model of tSZ maps: The student will build a framework to simulate realistic tSZ maps for a range of cosmological parameters and baryon feedback models. This forward model will combine a gravity solver (e.g. particle-mesh simulations) with an emulator that generates extragalactic foreground maps based on halo models such as XGPaint (Li et al., 2021).

2. Test the Gaussian likelihood assumption: Most tSZ-WL analyses assume a Gaussian likelihood for the angular power spectra. This project will quantify deviations of the true sampling distribution from this assumption. The student will generate large ensembles of simulated tSZ and WL maps using the forward model and apply neural density estimators to infer the sampling distribution of the power spectra. The student will assess whether the Gaussian approximation introduces biases in cosmological parameter inference and quantify them.

3. Develop a simulation-based inference framework: To capture information beyond the power spectrum, the student will apply the Hybrid Statistics approach (Makinen et al. 2025). This machine-learning technique defines an optimal data compression that retains the full non-Gaussian information. The student will validate the inference pipeline on simulated data and forecast the information gain relative to standard analyses.

4. Application to data: The student will apply the framework to *Euclid*'s weak lensing data and tSZ maps from Planck or the South Pole Telescope (SPT), which are publicly available. This tSZ-WL analysis will provide joint constraints on the cosmological parameters and baryon feedback.

Scientific environment

The PhD will be carried out in the CosmoStat laboratory at the Département d'Astrophysique at CEA Saclay, under the supervision of Natalia Porqueres, Emma Ayçoberry and Sam Farrens. The student will also closely collaborate with David Alonso at the University of Oxford. CosmoStat hosts a multidisciplinary team whose research includes statistics, machine learning, artificial intelligence, and cosmology. The group is strongly involved in the weak lensing analysis of the *Euclid* space mission.

Application

The candidate should hold a Master 2 degree (or equivalent) in either physics / astrophysics or applied mathematics / signal processing / data science. Experience with Python and Git is not required but would be advantageous. Applicants should send a CV and a summary of past research (max. 2 pages) to **nporqueresrosa@gmail.com** before the application deadline. In addition, applicants should arrange for 2 reference letters to be submitted directly to the same email. Early submissions are encouraged and inquiries about the position are welcome.