**PhD Project, 2023-2026**

# Joint Estimation of the Euclid PSF, Cosmic Shear, and Galaxy SEDs and Morphologies

**Application Deadline**: March 10th 2023

**Keywords**: gravitational lensing - deep generative models - large scale Bayesian inference

**Context**: The Euclid satellite will aim to map with unprecedented accuracy and scale the matter distribution in the Universe. It will do so in particular by measuring the so-called weak gravitational lensing signal (also known as cosmic shear). Measuring this signal requires exceedingly delicate measurements of galaxy shapes, which in turn relies on exquisite control of the Point Spread Function (PSF) of the instrument, but is also impacted by the details of galaxy morphologies and Spectral Energy Distributions (SEDs) which can induce biases. This last point is an especially important consideration for Euclid, as the wide optical band of the VIS imager induces significant wavelength dependence of the PSF.

**PhD project:** The goal of this project is to build a consistent forward model of the Euclid field of view accounting for the Euclid PSF, cosmic shear, and galaxy morphologies and SEDs, which is a principled and theoretically optimal way to jointly estimate the cosmic shear field all the while calibrating for PSF and morphology biases.
Making this problem tractable at the scale and complexity of Euclid will involve relying on state-of-the-art Deep Learning, Bayesian inference, and automatic differentiation tools and techniques.

The successful candidate will build on the significant expertise developed in this area within the CosmoStat laboratory at CEA Saclay. Complex galaxy morphology models have already been developed and have been demonstrated to be sufficiently complex to model realistic galaxies **[1]**. In addition, CosmoStat is already developing a forward model of the Euclid PSF, known as WaveDiff **[2]**. The goal of the project is therefore to bring all these elements together and demonstrate robust cosmic shear recovery and marginalization over PSF and SED uncertainties, for ultimate application to Euclid data.

In the first year, the candidate will continue to develop the WaveDiff PSF to match realistic Euclid simulations, and combine it with galaxy morphology models to demonstrate an ability to recover unbiased cosmic shear when marginalizing over PSF model errors. In the second year, the candidate will extend the model to include wavelength dependence and SED modeling for each galaxy, as well as jointly modeling several galaxies and the overall PSF model. The final year will aim to apply this model to Euclid data, and produce weak lensing shear and convergence maps for downstream scientific exploitation.

From a methodology point of view, this project involves using and developing state-of-the-art deep learning models and Bayesian inference tools. In particular Deep Generative Models will be used to characterize galaxy light profiles, and very efficient variational inference techniques will be applied to perform inference in high dimensions, and recover correct posterior estimates on the gravitational shear.

**Scientific environment**: The PhD will be carried out in the CosmoStat laboratory at the Departement d'Astrophysique at CEA Saclay under the supervision of Francois Lanusse, and benefiting from the experience of other CosmoStat group members Jean-Luc Starck and Martin Kilbinger. CosmoStat hosts a multidisciplinary team whose research includes statistics, signal processing, machine learning, and cosmology. The group is strongly involved in the weak gravitational lensing analysis of the upcoming Euclid mission and has a long tradition of developing cutting-edge statistical tools for the analysis of astronomical and cosmological data.

**Computational resources**: The successful candidate will have access to the Jean Zay supercomputer, largest GPU cluster for research in France. Most of the development will rely on GPUs, through the JAX and XLA libraries.

**Profile and skills required**: To be able to make progress on the core scientific challenges of the project, the successful candidate should already be comfortable with software development (at least in Python), and ideally be familiar with open source and collaborative development tools (e.g. GitHub). A background in signal/image processing, deep learning, statistical inference, or previous experience with processing astronomical images is not required but would be beneficial.

**Contact**:


- Dr. Francois Lanusse (francois.lanusse@cea.fr)


**References:**


[1] B. Remy, F. Lanusse, J.-L. Starck, Towards solving model bias in cosmic shear forward modeling, Machine Learning and the Physical Sciences Workshop at NeurIPS 2022

[2] T. Liaudat, J.-L. Starck, M. Kilbinger, P.-A. Frugier, Rethinking data-driven point spread function modeling with a differentiable optical model, 2022