PhD, 2023 - 2026

Weak gravitational lensing statistics for the Euclid space mission

Context

Weak gravitational lensing, the distortion of the images of high-redshift galaxies due to foreground matter structures on large scales is one of the most promising tools of cosmology to probe the dark sector of the Universe [1]. The statistical analysis of lensing distortions is one of the most promising tools to measure the properties of dark matter and dark energy.

The European space mission Euclid, to be launched in 2023, will determine cosmological parameters such as the dark-energy equation-of-state w, the total neutrino mass m_ν, and the growth index parameter γ to unprecedented accuracy [2]. To achieve this ambitious goal, Euclid will measure the shapes of 1.5 billion high-redshift galaxies.

Cross-correlations of weak-lensing distortions with spectroscopic galaxy surveys represent an additional intereting observable. They improve constraints on cosmological models, parameter degeneracies, and help to control systematic errors that affect weak-lensing and spectroscopic data in a different way. Cross-correlations have the potential to improve our knowledge about the complex relationship between galaxies and the underlying dark-matter distribution, and can shed light on the formation and evolution of galaxies in their dark-matter environments.

The PhD project

The goal of this PhD project is to develop all necessary tools for an efficient and reliable analysis of Euclid weak-lensing and lensing – galaxy cross-correlation data. Starting from the measured Euclid weak-lensing galaxy shapes and spectroscopic galaxy data from Euclid and other surveys such as BOSS, eBOSS, and DESI, the student will construct various estimators of lensing and cross-correlation observables. Combinations of these observables as function of scale, redshift, and galaxy properties will be optimised for maximally extracting cosmological information from the data. In addition, detailed modelling of systematic effects will be carried out to control and minimize their influence on the results.

The student will make use of, and further develop modern statistical inference tools for efficient parameter inference. Theoretical predictions of observables from models of the expansion history and large-scale structure of the Universe will be created in an automatic differentiation framework, e.g. using the library `jaxcosmo`, exploiting massive parallel computations on GPUs and the ability to compute gradients of the likelihood to accelerate inference. This will open up efficient (Bayesian) inference methods that make use of the gradients of the models with respect to parameters. Compared to traditional sampling techniques, these methods offer a significant computation time speed-up, and the ability to efficiently explore a large number of parameters. This is important for exploring non-standard models of gravity with additional parameters, and flexible models with many nuisance parameters. It also allows us to include detailed, time-consuming modelling of systematic and higher-order effects.

To model the non-linear regime, emulators will be explored, making use of recent advances in simulation-based, likelihood-free inference methods.

These methods will be tested using dedicated Euclid-internal simulations. Further, the codes developed here will be validated by comparing their outputs against the official Euclid likelihood modules. In addition, the student will develop novel diagnostic tests for lensing – galaxy correlations. These have an additional general benefits since they can be used also in the context of weak lensing by galaxy clusters and voids, and weak-lensing peak counts.

Outline of the project

The tasks and objectives of this PhD project are as follows.

1. Get familiar with weak-lensing and lensing - galaxy cross-correlation statistics, and their theoretical predictions using automatic-differentiable codes.

2. Study various lensing and cross-correlation estimators. Implement systematic effects in the model prediction. Explore combinations of estimators to maximise cosmological information, and minimize systematic errors.

3. Develop diagnostic tools for lensing - galaxy cross-correlations.

4. Test and validate the methods developed here using Euclid simulations and the traditional Euclid likelihood module.

Methods

Correlation analysis of large datasets of weak lensing and spectroscopic galaxy surveys — automatic differentiation methods — Bayesian parameter inference — modelling of cosmological observables.

Scientific environment

The PhD will be carried out in the CosmoStat laboratory at the Département d'Astrophysique at CEA Saclay, under the supervision of 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-lensing analysis of the upcoming mission Euclid. Kilbinger was the deputy of the Euclid Weak-Lensing Science Working Group from 2015 to 2022, and is science coordinator of the weak-lensing correlation function code implementation.

Requirements

The candidate should have a Master 2 degree (or equivalent) in physics, astronomy, applied mathematics, or a related field. Experience with python is not required, but would be advantageous.

The application deadline is 15/03/2023.

Contact

Martin Kilbinger, `martin.kilbinger@cea.fr`
CEA/Irfu/Dap, Laboratoire AIM
Orme des Merisiers, Bât 709, office 283
F-91191 Gif-sur-Yvette

References

[1] Kilbinger, M., *Reports on Progress in Physics*, 78(8):086901, 2015.

[2] Euclid Collaboration, Blanchard, A., Camera, S., et al., *A&A*, 642:A191, 2020.