PhD thesis project, 2021 – 2024

"3x2pt" analysis: Cross-correlations of cosmological probes, and application to state-of-the-art weak-lensing and galaxy clustering surveys.

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. In addition, the observed distribution of galaxies, or **galaxy clustering**, provides us with a picture of the evolution of the cosmic web in three dimensions. Together, both of these cosmological probes help us to connect the formation of galaxies to dark matter, and to shed light on the unknown origin of the accelerated expansion of the Universe. Whether this acceleration is due to a simple cosmological constant, a yet to be discovered "dark-energy" fluid, or indicates that gravity and Einstein's theory of General Relativity have to be modified at very large scales, is one of the most important problems of modern physics.

The statistical analysis of both weak gravitational lensing and galaxy clustering relies on the measurement of the two-point (2pt) correlation function for each probe, quantifying the "lumpiness" of the matter distribution at different scales. This is complemented with the **galaxy-galaxy lensing correlation function**, quantifying the lensing distortions by foreground galaxies. The analysis of the combined three data vectors is called in short "3x2pt".

A simple addition of weak gravitational lensing and galaxy clustering neglects **cross-correlations between the 3x2pt functions**. These functions are not independent since they probe the same large-scale structure. The cross-correlations quantify the relation between their different components. To properly account for them is crucial to constrain dark energy and modified gravity. The cross-correlation terms are in fact additional observables, boosting the constraints on cosmological parameters.

So far, the computation of these cross-correlations have been tested within a ΛCDM scenario, most recently in the Euclid collaboration under the lead of CosmoStat member Valeria Pettorino. It is however not straightfoward to extrapolate these calculations to extended cosmological models.

The PhD project

The goal of this PhD thesis is to carry out a 3x2pt analysis of data from state-of-the-art galaxy surveys:

- Weak-lensing data from the **Ultraviolet Near-Infrared Optical Northern Sky (UNIONS)**[1], an ongoing large imaging survey that will cover $5,000$ deg^2 in the Northern sky in multiple

[1] `https://www.cosmostat.org/projects/unions-cfis`

optical bands. Lensing distortions of galaxies on around half of that area, to date, have been measured by CosmoStat under the lead of Martin Kilbinger.

- 3D galaxy clustering data from the **Dark Energy Spectroscopic Instrument (DESI)**[2]. First science data from DESI are expected in early 2021. IRFU is member of DESI, and the student will have full data access. DESI will be complemented by public data from the (Extended) Baryon Oscillation Spectroscopic Survey (BOSS, eBOSS)[3].
- Weak-lensing and galaxy clustering (both in 2D and 3D) data from **Euclid**[4]. Euclid is the next major cosmology space mission from ESA, to be launched in 2022. Euclid will observe one 150 billion galaxies over the observable sky outside the Milky Way and the ecliptic, in optical and infrared wavelengths.

The main objectives of this PhD are:

1. Get familiar with existing weak-lensing and galaxy clustering analysis and likelihood methods and codes, including their cross-correlations.
2. Analyse existing data from UNIONS and (e)BOSS/DESI including the cross-correlation between both surveys. Obtain first results on tests of modified gravity models beyond ΛCDM.
3. Further develop these methods for next-generation data from Euclid. Apply the methods to Euclid simulations.

These objectives are aimed towards the development of an optimal use of weak lensing and galaxy clustering for upcoming surveys, to take steps towards confirming or disproving the standard theory of Einstein, opening a path to new insights into fundamental physics.

Scientific environment

The thesis will be carried out in the CosmoStat[5] laboratory at the Département d'Astrophysique[6] (DAp) at CEA Saclay, under the supervision of Martin Kilbinger and Valeria Pettorino. CosmoStat hosts a multidisciplinary team whose research includes statistics, signal processing, machine learning, and cosmology. CosmoStat members are leading the weak-lensing analysis of UNIONS/CFIS. The group is strongly involved in the scientific preparation of Euclid. Martin Kilbinger is co-lead of the Weak Lensing Science Working Group of Euclid. Valeria Pettorino is lead of the combined-probe likelihood analysis of Euclid data.

The Phd student will work at the interface between observations and theory, and learn about cosmological data analayis as well as modified gravity. State-of-the art statistical methods and machine-learning applications will be used. The student will learn a variety of different skills, both in the analysis and interpretation of data, with a concrete impact on future cosmological experiments. The lab environment perfectly fits the topic of the thesis to facilitate the feasibility of the project. The student will be able to help in the organization of meetings and develop

[2] https://www.desi.lbl.gov
[3] https://www.sdss.org/surveys/eboss
[4] http://sci.esa.int/euclid
[5] http://www.cosmostat.org
[6] http://irfu.cea.fr/Sap/

transferrable competences, both in problem solving and in numerical analysis, that will be useful for a future careers either in academia or in the industrial domain.

Requirements

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

The application deadline is 15/04/2021.

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