Stage M2, 2025

Uncovering the three-dimensional cosmological tidal field.

Context

As galaxies form in the Universe they are shaped by the surrounding matter tidal field. Therefore by studying the shapes and orientations of galaxies we can learn about the tidal field in which galaxies form. This leads to galaxies having correlated shapes across the sky, this effect is referred to as intrinsic alignment.

Intrinsic alignment is of interest for many reasons. Firstly, if correctly modelled it can provide us interesting information on the matter content and the growth of structure in the Universe. It can help us to learn more about the environments in which galaxies are formed, and how the tidal field effects galaxy formation. Finally, intrinsic alignment is an important systematic for weak gravitational lensing surveys, one of the most powerful probes of dark matter and dark energy. Understanding and modelling intrinsic alignment is necessary to correct for its effects on weak gravitational lensing, such as the observations currently being taken by the Euclid satellite [1].

Several studies have used two-dimensional shape correlations of galaxies to estimate the amplitude of the intrinsic alignment signal (for example: [2]). However information contained in the observations about the third dimension, the alignment signal perpendicular to the line-of-sight has been ignored in previous analysis. Uncovering this additional information could significantly improve our understanding of intrinsic alignments and their connection to the cosmological tidal field, giving us a more complete three-dimensional picture of how galaxies respond to the surrounding large-scale structure of the Universe.

The UNIONS survey has mapped the northern sky and measured the shapes of almost 100 million galaxies and also provides key ground-based photometry for the Euclid space mission. As UNIONS overlaps with spectroscopic redshift surveys such as SDSS and DESI, we can have precise redshift information as well as shape measurements. Therefore UNIONS is an excellent survey to use to study intrinsic alignments. The Cosmostat group at CEA, Saclay are involved in the processing and scientific analysis of both UNIONS and Euclid.

This Internship

This internship will focus on developing a novel approach to estimate the 3D orientations of galaxies from their observed two-dimensional images and eventually measuring the correlations between 3D shapes of galaxies with UNIONS and SDSS data. If successful this would be the first measurement of 3D correlations between galaxy images. This will serve as an important precursor study with future Euclid data and will hopefully improve our understanding of intrinsic alignment and the tidal matter density field.

Outline of the Project

The specific tasks and objectives of the internship are as follows:

1. Develop an understanding of galaxy morphology and the connection between

projected shapes and intrinsic 3D shapes of galaxies.

2. Work with the large galaxy shape catalogues of UNIONS and combine the data with SDSS redshifts.
3. Develop an estimator for the 3D shape of galaxies from their projected images.
4. Measure the 3D shapes of galaxies on the sky.
5. Infer physical properties about the intrinsic alignment field using Simulation Based Inference (SBI).

Each task will involve working with real and simulated datasets, applying statistical analysis techniques, and contributing to the development of tools that can eventually be used in Euclid's weak lensing analysis pipeline.

Methods

Depending on the intern's interests and expertise, several different methodologies can be applied throughout the project. Potential methods include:

- **Simulation-based inference**: Use simulations to model galaxy formation and alignments, and to test the relationship between galaxy morphology and the tidal field.
- **Halo Occupation Distribution (HOD) models**: These models describe how galaxies are distributed within dark matter halos. By incorporating 3D orientation information, we can develop a more realistic HOD model including intrinsic alignments.

This internship offers the opportunity to contribute to a cutting-edge area of cosmological research and participate within UNIONS and Euclid.

The intern will acquire skills in handling large astronomical datasets, developing statistical models, and working with cosmological simulations. Depending on the outcome, this project could lead to novel constraints on the tidal field and its role in galaxy formation.

Scientific environment

The stage will be carried out in the CosmoStat laboratory at the Département d'Astrophysique at CEA Saclay, under the supervision of Calum Murray 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-lensing analysis of the upcoming mission Euclid.

Requirements

The candidate should be a master 2 (or equivalent) student with a background in either physics/astrophysics or applied mathematics/signal processing/data science. Experience with python is not required, but would be advantageous.

The application deadline is 15/12/2024. The duration of the internship is 4 – 6 months. This internship work can potentially be continued as a PhD in our group.

Contact

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References

[1] Euclid Collaboration, Mellier, Y., et al., *arXiv:2405.13491, A&A in press*, 2024.

[2] Singh, S. & Mandelbaum, R., *MNRAS*, 457(3):2301–2317, 2016.