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PhD position, 2027– 2030

Probing dark matter in galaxy cluster cores with weak gravitational lensing flexion from the Euclid space satellite

Context

Weak gravitational lensing, the distortion or *shear* 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, 2]. Weak lensing by galaxy clusters is particularly interesting for cosmology. Galaxy clusters, collections of hundreds to thousands of galaxies, are the most massive bound structures in the Universe. They are key probes for cosmology: measurements of their abundance, i.e., the number of clusters as a function of mass and redshift, can provide strong constraints on dark energy. In addition, cluster density profiles can shed light on the particle nature of dark matter. The amount of sphericity of cluster mass distributions and its evolution with cluster-centric radius can provide valuable information about properties of dark matter such as its interaction rate in models of self-interacting dark matter.

The European space satellite Euclid, will survey $14,000$ deg^2 of sky over the next five years [3]. A first data release of $1,900$ deg^2 sky area is underway. The combination of area, depth, and space-quality angular resolution from Euclid will make it possible to map the dark matter structure of hundreds of thousands of massive galaxy clusters with weak lensing.

The key is to access the dense, dark-matter regions just outside the cluster core, which are ideal to measure dark-matter properties. These regions are underexplored to date and often removed from the analysis due to non-linear biases and higher-order lensing distortions, the so-called *flexion*, in this not-so-weak lensing regime. The measurement of flexion as a signal can improve cluster mass constraints by a factor of two [4]. However, the measurement of the small, higher-order distortions on faint galaxies is very challenging, and only space-based observations such as Euclid can provide the required excellent image quality. To this end, the student will develop methods that go beyond the standard Euclid ground segment pipeline, which does not include non-linear calibration or flexion.

The goal of this PhD is to measure, for the first time on a large sample of clusters, weak-lensing flexion with Euclid's space-based imaging, and to combine it with shear to constrain the inner mass profiles of galaxy clusters, deriving constraints on the self-interaction rate of the dark matter particle.

Outline of the project

The tasks and objectives of the thesis are as follows.

1. Get familiar with weak-lensing observations, and galaxy clusters in the context of cold dark matter and self-interacting dark matter models.
2. Access Euclid weak-lensing data in cluster fields, and carry out the standard analysis using code from the Euclid ground segment pipeline.
3. Develop methods for higher-order lensing effects, to measure flexion and calibrate non-linear biases. The student will start working with an extension of the `SourceXtractor++` code developed by collaborators in Marseille and at the supervisor's lab [5]. For calibration, Euclid image simulations are accessible to the student.
4. Measure cluster mass profiles by bringing together the developed methods of calibration and flexion estimates, and interpret the results in the context of cold dark matter (CDM) and self-interacting dark matter models. N-body simulations with flexion for CDM and non-CDM models have been shared with the supervisor by a collaborator in the lab [6].

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 space mission Euclid.

Requirements
The candidate should have a master 2 (or equivalent) degree with a background in either physics/astrophysics or applied mathematics/signal processing/data science. Experience with python is advantageous. The application deadline is 01/03/2027. Funding for this PhD is pending selection of the candidate and topic by CNES and/or the Doctoral School. If funding is acquired, the PhD starting date is October 2027.

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References

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