Galaxy Cluster detection with Weak Lensing: Towards a Euclid Weak Lensing galaxy cluster catalogue

Context

Euclid is an ESA mission important for cosmology and internationally renowned, planned to be launched in 2022. The AIM laboratory, initiator of the project, has quite a few Euclid key positions in management, instrumental development, ground segment and related science. AIM is also strongly involved in the ongoing CFIS survey (PI: Jean-Charles Cuillandre) that has to provide some of the ground-based data necessary for the Euclid mission.

The sensitivity of Euclid should allow *blind* detection of clusters through their lensing signal i.e. directly through their total projected mass. Combined with the sky coverage, this will allow the construction of a significant galaxy cluster catalogue that is for the first time truly representative of the true cluster population, because up to now all galaxy cluster catalogues rely on detection through their baryonic signal (e.g. through the intracluster gas content in X-rays and the Sunyaev-Zeldovich effect (SZE) at millimetre wavelengths, or through the optical light in the galaxies). This will provide new constraints on galaxy cluster abundances in the Universe, which has important implications for cosmology.

In this context, AIM is also deeply involved in the ongoing XMM-Heritage project (PI: Monique Arnaud, AIM) that is a multi-year programme to obtain X-ray observations with XMM-Newton of 118 SZ-selected galaxy clusters at $0.05 < z < 0.6$. A key project goal is to obtain X-ray data with homogeneous quality for the first time for such a large number of objects. Crucially, object selection was tailored specifically to the CFIS and Euclid survey areas.

The thesis will be conducted in this very stimulating context.

Research project

The thesis project aims at building the weak lensing galaxy cluster catalogue (initially CFIS, and ultimately Euclid) using innovative methods and contributing to its scientific exploitation by combining it with the XMM-Heritage sample.

In the first part of the thesis the candidate will design a method to detect galaxy clusters blindly based on their lensing signal. The first catalogue of galaxy clusters detected with weak lensing has been produced by HSC (Miyazaki et al. 2018). However, in this study, the detection algorithm is not fully adapted to galaxy cluster detection. In this work, we will design a new method of galaxy cluster detection through the weak lensing effect. Using the convergence maps as a starting point, we will use priors on the expected lensing signal from clusters, in conjunction with multi-resolution wavelet decomposition. Using realistic mock observations derived from cosmological numerical simulations, we will build a sample of weak lensing-detected galaxy clusters and assess its associated completeness and purity. The methods developed above will be applied to CFIS data to obtain a weak lensing selected cluster catalogue. As the object selection strategy of the Heritage project cannot exclude the existence of baryon-poor clusters that are simply not detected in X-ray or SZE surveys, comparison of the Heritage sample with weak lensing selected cluster samples in the CFIS survey areas will give fundamental insights into cluster selection.

The second part of the thesis will focus on developing an unbiased mass estimate for the lensing-selected cluster sample. For this purpose, the candidate will develop a new method of cluster mass estimation from the lensing signal based on the convergence and will compare it with the existing methods based on the shear. For this study, understanding the systematic effects of the cluster mass estimation from the lensing signal is crucial (Pratt et al. 2019). In particular, since lensing measures the projected (2D) mass, it will be necessary to investigate methods to obtain the true (3D) mass from the projected signal. Then, comparison of the XMM-Heritage with the high quality individual and/or stacked total mass profiles from CFIS data will allow unbiased statistical studies of these profiles. These studies will allow to quantify and compare the radial distribution of dark matter and baryons, which are fundamental probes of physics and cosmology.

Ultimately, the codes developed in the course of this thesis will be integrated in the Euclid pipeline (by a software engineer) and will allow to produce the Euclid weak-lensing selected cluster catalogue that will be delivered to the community.

Scientific environment

The thesis will take place in the Astrophysics Department of CEA Saclay (UMR AIM), at the interface of the Galaxy Clusters and the CosmoStat groups. The CosmoStat group is recognised for its expertise in Signal processing, it hosts a multidisciplinary team whose research include statistical methods, signal processing, and cosmology. CosmoStat members are currently working on the weak-lensing analysis of CFIS and in the preparation of the upcoming Euclid mission (to be launched in 2022) where the group is strongly involved. The Galaxy clusters group uses multi-wavelength (optical, X-ray, mm) data to probe the properties of galaxy clusters. They have extensive experience of X-ray observations, and were key members in the construction and exploitation of the cluster catalogue from the Planck SZ survey. The supervision of the thesis will be jointly performed by Sandrine Pires (Astrostatistician and Weak Lensing expert) and Gabriel W. Pratt (Galaxy Cluster expert). S. Pires is a member of Euclid, CFIS and the XMM-Heritage collaboration. She has a strong expertise in weak lensing dark-matter maps and she has several leading positions in Euclid in this context and in particular she is in charge of the production of the Weak Lensing Cluster catalogue and its scientific exploitation. G.W. Pratt is a member of the XMM-Heritage collaboration Steering Committee, in addition to Euclid and Athena.

This thesis will be carried out in close collaboration with Monique Arnaud (PI of Heritage, AIM), Jean-Charles Cuillandre (PI of CFIS) and Jean-Baptiste Melin at DPhP (Planck and Euclid cluster expert, DPHP).

References

Miyazaki, S., Oguri, M., Hamana, T., et al. 2018, PASJ, 70, S27

Pratt, G. W., Arnaud, M., Biviano, A., et al. 2019, Space Sci. Rev., 215, 25