PhD thesis, 2019 – 2021

Cosmology with gravitational waves and galaxy clustering: synergie between LISA and Euclid

Context

The recent direct detections of gravitational waves (GW) from mergers of massive compact objects has opened a new window to our Universe. The GW signal allows us to measure the luminosity distance to the merger, from which we can constrain the expansion history of the Universe, including the Hubble constant H_0 and dark-energy properties. However, most GW events are expected to have no detectable electro-magnetic counterpart. We thus have to employ statistical analyses to use these events in a cosmological context. The spatial distribution of galaxies, or galaxy clustering, can help us to infer the redshift of a population of events in a statistical way [1, 2]. The interpretation in a cosmological context of the resulting Hubble diagram needs to account for this statistical redshift estimation.

Work to date has focused on spectroscopic galaxies. By extending this to galaxy surveys in broad-band photometry the number and limiting magnitude of available galaxies for clustering analysis can be vastly increased. The challenge in this approach is the determination of precise redshifts. In addition, photometric surveys with excellent image quality allows us to map the dark-matter distribution along the line of sight due to weak gravitational lensing. This helps to reduce the induced magnification of the GW luminosity, one of the dominant systematic effects at high redshift.

This project aims to estimate the impact of redshift estimation on the clustering analysis of GW events for cosmological parameter inference. The synergie between GW experiments and galaxy surveys will be exploited. Forecasts will be done for the future space mission LISA[1] (launch planned for 2034) and Euclid[2] (launch in 2022), to assess their performance in a joint analysis to measure the expansion history of the Universe.

Outline of the project

The tasks and objectives of the thesis are as follows.

1. Familiarization: Study the statistical analysis of GW events, redshift estimation of photometric surveys, weak gravitational lensing, and modelling of the large-scale galaxy distribution.
2. Error estimation: Quantify the uncertainties in the statistical redshifts of the GW host galaxies. Assess the systematic errors on the GW luminosity due to weak gravitational lensing, and the possible correction of this contamination using the predicted performance Euclid.
3. Modelling: For a GW population expected to be detected by LISA, develop models of the host galaxy distribution in the large-scale strucure. Use the results from the previous task to assess the model uncertainty.
4. Forecasts: Predict the performance of LISA and Euclid to measure the expansion history of the Universe using the above developed techniques. Compare the expected constraints on cosmological

[1] https://www.elisascience.org
[2] https://www.euclid-ec.org

parameters to other probes such as observations of nearby GW with EM counterparts (NS - NS mergers), gravitational lensing, CMB, and SNIa.

Methods

During the thesis, the student will work on methods of galaxy redshift estimation. This includes photometric redshifts, clustering redshift [3], and machine learning techniques. The student will use reconstruction techniques of dark-matter maps from weak lensing data. For the modelling of the galaxy distribution, numerical simulations and fast approximate methods will be employed [4]. Bayesian methods of parameter inference will be applied on these models, including Approximate Bayesian Computation (ABC) [5, 6].

Scientific environment

The PhD will be carried out in the CosmoStat[3] laboratory at the Département d'Astrophysique[4] (DAp) 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 CosmoStat group is strongly involved in Euclid (launch in 2022). Kilbinger is the co-lead of the Weak-Lensing Science Working Group in Euclid. This thesis is carried out in collaboration with Antoine Petiteau (APC, expert in gravitational wave detection and data analysis, French responsible of LISA Pathfinder), and Emille Ishida (Clermont-Ferrand, expert in parameter inference methods and machine learning).

References

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