PhD thesis, start autumn 2020

Targeting gravitational waves with optical surveys: synergy between Euclid and the Chinese Space Station Telescope (CSST)

Context

The recent direct detections of gravitational waves (GW) from mergers of massive compact objects has opened a new window to our Universe. The electro-magnetic (EM) counterpart of the event GW170817 [1] started a new multi-messenger era for astronomy. Joint GW and EM observations provide a way to better understand the physics and rate of violent processes of black hole and neutron star mergers, and the properties of their host galaxies and stellar populations. GW as standard sirens, together with the host galaxies' redshift, measure the expansion history of the Universe including the currently contested value of the Hubble constant H_0 and dark-energy properties.

To identify GW transients via quick follow-up observations across the EM spectrum, galaxy surveys from ultra-violet (UV), optical, to infrared (IR) wavelengths are of great importance. The localization volume of LIGO/VIRGO[1] can contain tens of thousands of potential host galaxies over a large area, making EM identification challenging even for wide-field telescopes. An alternative strategy is to use deep imaging surveys for targeted searches. These surveys need to be complete to low galaxy luminosity and stellar mass, providing a complete galaxy census to reduce selection biases. In addition, efficient automated techniques need to be employed for rapid target selection. In case of "dark" GW events, marked by the absence of a detectable electromagnetic counterpart, galaxy surveys can provide a statistical measurement of the GW host galaxy redshift. Note that the large majority of GW events stem from black-hole mergers, and will therefore likely be dark. In addition, optical surveys with high image quality will provide weak-lensing maps of the dark matter in the Universe. From these maps we can draw information about the weak-lensing magnification of gravitational waves, which is the major systematic uncertainty to determine the luminosity distance of a GW event at $z > 0.3$.

This PhD project will explore the synergy and complementarity of two upcoming space missions, the ESA satellite Euclid[2] [2] (launch in 2022), and CSST, the Chinese Space Station Telescope [3] (planned for 2024). Both missions will cover a large fraction of the extra-galactic sky with a common area of $15,000$ deg^2. Euclid will provide images of very high quality in the visible wavelengths, ideal for weak gravitational lensing. In addition, near-IR imaging and spectroscopy will provide redshifts at high z. CSST will provide imaging and spectroscopic data in UV and optical bands for very accurate photometric redshifts. The UV images will help to clearly identify small galaxies at $z < 0.3$.

Existing ground-based data is available for this project: The Ultraviolet Near-Infrared Optical Northern Survey (UNIONS), a collaboration between the Canada France Imaging Survey [4] and Pan-STARRS. This ongoing survey (2017-2023) is at the half-way completion point of covering 4,800 deg^2 in the Northern sky in the photometric bands u, g, r, i, and z, with excellent image quality in r with which our group carries out weak-lensing measurements. Data processing has been optimised to find low-surface brightness and diffuse galaxies [5].

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

UNIONS/CFIS will increase size, depth, and completeness of existing surveys [6] by two orders of magnitude over the Northern sky, necessary for the large GW distances that will soon be reached by LIGO/VIRGO. Euclid + CSST data will provide the reference deep survey for targeting of LIGO/VIRGO and, ultimately, the space GW detector LISA[3].

Outline of the project

The tasks and objectives of the thesis are as follows.

1. Familiarise with the basics of GW events and EM counterparts, and galaxy surveys for targeting, follow-up observation, and redshift estimation.
2. Create a target catalogue from UNIONS/CFIS data.
3. Develop machine-learning based target selection methods for rapid follow-up strategies.
4. Adopt and (if necessary) modify target selection methods for Euclid + CSST.
5. Estimate the expected accuracy of weak-lensing magnification maps from Euclid + CSST, and assess how this reduces the systematic error on the luminosity distance of LISA GW events at high redshift.

Scientific environment

The PhD will be carried out in the CosmoStat[4] laboratory at the Département d'Astrophysique[5] (DAp) at CEA Saclay, under the supervision of Martin Kilbinger and Samuel Farrens. CosmoStat hosts a multidisciplinary team whose research includes statistics, signal processing, machine learning, and cosmology. The CosmoStat group is strongly involved in Euclid, and collaborates with the cosmology group of CSST (Lead: Zuhui Fan). Kilbinger is the co-lead of the Weak-Lensing Science Working Group in Euclid. DAp also hosts the French PI of UNIONS/CFIS, Jean-Charles Cuillandre. This thesis will be carried out in collaboration with Dr. Fan and the CSST cosmology team.

References

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[5] Ferrarese, L., Côté, P., Sánchez-Janssen, R., et al., *ApJ*, 824(1):10, 2016.

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Contact

Martin Kilbinger
✉ martin.kilbinger@cea.fr
http://cosmostat.org/people/kilbinger
☎ +33 1 69 08 17 53
Office 280

Samuel Farrens
✉ samuel.farrens@cea.fr
http://cosmostat.org/people/sfarrens
☎ +33 (0)1 69 08 83 77
Office 279

CEA/Irfu/Sap
Laboratoire AIM, Bât 709, Orme des Merisiers
F-91191 Gif-sur-Yvette

[3] https://sci.esa.int/web/lisa
[4] http://www.cosmostat.org
[5] http://irfu.cea.fr/Sap/