Titre : Suivi des alertes d'ondes gravitationnelles de LIGO/Virgo par le réseau GRANDMA.

Title : Follow-up of LIGO/Virgo gravitational wave alerts by the GRANDMA network.

PhD advisor : Patrice Hello, IJCLAB, Orsay.

The GRANDMA network (created at IJCLAB) embeds more than 25 telescopes covering grossly all time zones and both hemispheres. The primary goal of GRANDMA is to follow-up on Gravitational Waves alerts provided by LIGO and Virgo. The next LIGO-Virgo run (O4) will start in December 2022 so in perfect timing with this thesis project. As during previous runs, LIGO-Virgo will provide low latency alerts in case of gravitational waves candidates so that optical telescopes can rapidly follow-up on the most interesting candidates (e.g. mergers with at least a neutron star). The goal is first to identify the optical counterpart and the host galaxy and second to characterize it by photometric methods (obtaining the lightcurves of kilonovae for instance) or spectroscopic ones. GRANDMA has demonstrated [1] during the previous LIGO-Virgo O3 run that the network was able to follow-up most of the alerts with a very good latency (less than 90 minutes latency for 50% of the alerts with 15 minutes record). This is particularly crucial for observations of kilonovae which are expected to fade very rapidly. For instance, catching the very first points of kilonova lightcurves is important for extracting the most of physics from the observations and constraining the models. Estimation of the mass of the ejecta can constrain the equation of state of the neutron star(s) of the initial system. Estimation of the fraction of heavy elements (such as lanthanides) produced by the r-process can also be derived from light curves as well as from spectra.

A dedicated photometry pipeline (MUPHOTEN [2]) has been built at IJCLAB in the GRANDMA framework. The pipeline is able to estimate the image background, perform the substraction of a reference image in case there is a host galaxy, extract the magnitude of the detected transient. Additional features such as vetoes can be used to estimate the quality of the images and reject them if needed. This kind of feature is welcome when many images coming from different observation sites and with various sky conditions (e.g. more or less cloudy nights, light pollution …) are to be treated as fast as possible. If no transient can reliably be identified as the gravitational wave counterpart, the pipeline can establish the limit magnitudes (sensitivity) reached by all the telescopes involved in the follow-up. Starting from this, we can derive upper-limits for important parameters such as the ejecta mass.

In this context, the PhD student will participate to the GRANDMA follow-up of O4. LIGO/Virgo expect in average ~ 1 alert per day. In particular, questions about optimization/prioritization of the telescope network in case of multiple (coincident) alerts will arise. In case of a close binary neutron star merger (like GW170817) or neutron star-black hole merger, systems for which optical counterparts are expected, the first goal is to search for the counterpart. If such a counterpart is detected, then the goal is to characterize it: identification of the host galaxy, identification of the possible kilonova, building of the kilonova lightcurves, obtention of spectra…If no counterpart can be identified then we provide upper limits on optical fluxes through the estimation of limit magnitudes of images taken by the telescopes. The next step is the interpretation of all collected data (with or without a counterpart) and the estimation or upper-limits on physical parameters such as the mass of the ejecta. The final step is to help constraining the models, in particular concerning the equation of state of nuclear matter in neutron stars. This phenomenology part will be done within a working group involving theoreticians specialists of neutron star physics [3].

.

[1] GRANDMA observations of advanced LIGO's and advanced Virgo's third observational campaign, S. Antier et al. MNRAS 497, 5518 (2020). https://arxiv.org/abs/2004.04277

[2] P.-A. Duverne, PhD thesis, IJCLAB.
[3] J. Margueron et al: BNICE, Binary neutron star mergers: nuclear inputs, machine learning and observations, proposal to ANR (2021).