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Multi-messenger observations of black hole-neutron star mergers in the O4 run

Black hole –neutron star (BHNS) binaries are among the least known objects in the Universe. Only recently were we able to observe them for the first time, and not via the traditional channel of electromagnetic (EM) waves, but through the new window of gravitational waves (GWs). In January 2020, the detectors of the LIGO/Virgo/KAGRA collaboration (LVK) detected two GW signals compatible with BHNS mergers, GW200105 and GW200115, which were then followed by few other candidates. BHNS mergers are expected to produce kilonova (KN) and short gamma-ray burst (SGRB) emission. The former is powered by nuclear-decay of heavy r-process elements, inside the NS material ejected during the merger. The SGRB emission is instead linked to the launch of a relativistic jet, following the formation of an accretion disk around the merger remnant. It is divided into SGRB prompt, due to bulk energy dissipation in the jet, and afterglow, due to the interaction with the ambient medium. Unfortunately, no BHNS GW detection has yet been associated with an EM counterpart, possibly due to either poor sky-localization, or the absence of any emission at all. The increase in the number of observed sources in future observing runs, and the detection of EM signatures, will allow to constrain the properties of this mysterious class of sources, and shed light on aspects such as component BH mass and spin distributions, merger rate densities and formation channels.

For these reasons, predictions of the number of sources detectable during future GW network observing runs, as well as the properties of the expected EM emissions, will be of extreme value in order to organize the EM follow up campaigns to GW events, and enhance the probability of catching these rapidly-fading transients. I am currently working on a related project in collaboration with the University of Milano-Bicocca, which I am going to present. We developed a self-consistent method to compute the GW, EM and joint GW+EM detection rates during the imminent O4 observing run of the LVK network. Our approach is based on simulating a synthetic population of BHNS merging binaries, and inferring the properties of the ejected matter as a function of the binary parameters via numerical-simulation-informed fitting formulae. The core of our work consists in a suite of semi-analitical models to compute the kilonova, SGRB afterglow lightcurves in different frequency bands, and SGRB prompt emission fluxes, as a function of the ejecta properties. Simulating also the GW signal, and imposing appropriate detection thresholds, allows us to finally obtain the GW, EM and joint GW+EM detection rates, considering different observing scenarios. Our work tries to answer fundamental questions such as: do all BHNS mergers produce an EM counterpart? Which counterpart can be detected in wide-area surveys or targeted observations? How long after the merger do we expect to detect the KN and afterglow emissions in a given frequency band? The comparison between our predictions and what will be actually observed during O4 will help dispel the mistery around the properties and evolutionary path of these sources.

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