Prospects and challenges for Opt/NIR counterparts of gravitational wave sources in the Rubin/ET era

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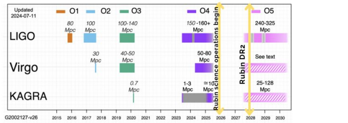
Abstract

Vera Rubin-LSST will play a key role in the newborn multi-messenger astronomy field allowing us to study and identify the likely faint and rapidly fading electromagnetic counterparts of the hundreds gravitational wave (GW) events expected by the 2nd generation GW detectors network at full sensitivity. It also will operate in synergy with other multi-wavelength facilities available for our teams GRAWITA (GRAvitational Wave INAF TeAm) and ENGRAVE (Electromagnetic counterparts of gravitational wave sources at the Very Large Telescope) expressly dedicated to this project. Here we present all the activities we are carrying out to optimize the response of the Italian and European network of facilities to expected GW triggers, and how the team is working in the context of the search for electromagnetic counterparts of GW sources and their spectroscopic characterization, also in anticipation of the arrival of the Einstein Telescope, in which our large community is involved. All the activities are expected to provide means and opportunities to the Italian and European astronomical communities to have a leading role in the GW and Time Domain Astronomy.

Introduction

The initial detection of the first binary neutron star merger in gravitational waves (GW), known as GW170817, has occurred during the LIGO-Virgo observing run O2. Despite the success of rapidly localizing this event and conducting an unprecedented follow-up campaign, subsequent efforts in observing run O3 involving over a dozen neutron star mergers failed to identify a credible electromagnetic (EM) counterpart. This led to the realization that deeper optical surveys are necessary for identifying such counterparts. Rubin Observatory with its significant advancements in depth and survey speed compared to current facilities is poised to play a critical role in identifying substantial samples of EM counterparts of GW sources. Its strengths will become increasingly crucial in subsequent GW observation operations, particularly with improved spatial localizations from KAGRA and LIGO-India. While these advances reduce the need for extremely wide-field instruments, the heightened sensitivity of GW interferometers implies that the detected sources will be farther away, posing a challenge in identifying faint EM counterparts.

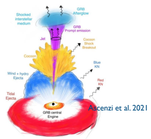


04 volume = 3*03 volume
05 volume = 15*03 volume
https://observing.docs.ligo.org/plan/

Projected observing scenarios for LIGO, Virgo, and KAGRA

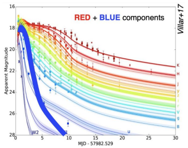
EM counterparts of GW sources studies with Rubin LSST

- Population studies: mapping the diversity of binary neutron star (BNS) merger outcome

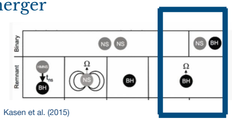


Ascenzi et al. 2021

- Kilonovae (KN) Blue component + discovery of new emission components



- Discovery of a EM counterparts of a BH-NS merger



Kasen et al. (2015)

- EM counterparts of BH-BH merger

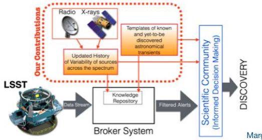
- EM counterparts of unidentified GW sources

Rubin TVS - Multi-wavelength and GW follow-up sub-group

MODE A HOW CAN WE WORK?

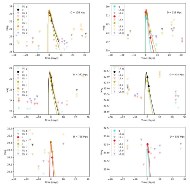
Rubin-LSST as a discovery machine

Other facilities perform follow-up of LSST transients

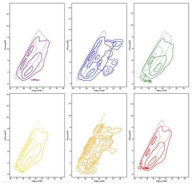


Margutti et al. from LSST science support proposal

- Maximize chances of first or second night counterpart candidate identification for multi-wavelength follow-up with other telescopes
- Ability to distinguish the counterpart from most "contaminants"
- Kilonova parameters estimation



Examples of synthetic GW170817-like kilonovae light-curves found serendipitously in the Rubin-LSST simulated baseline cadence.
(Fig. 1 from Andreoni et al. 2021)



Peak magnitude (X axis) and duration (Y axis) distributions extracted from KN light curve above the limiting magnitude are shown.
(Fig. 6 from Ragosta et al. 2024)

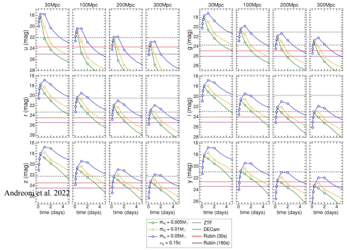
Rubin TVS - Multi-wavelength and GW follow-up sub-group

MODE B HOW CAN WE WORK?

Rubin-LSST as a follow-up machine

GW detectors find sources

- Selection of which GW triggers to follow-up (localization < 100 deg^2?)
- Rapid ToO observations
- Multiple timescales for "red" or "blue" kilonovae (or GRB afterglow)
- Deep exposures might be needed for distant mergers



Andreoni et al. 2022

Simulated KN light curves in the six Rubin filters for different properties of the ejecta (mass and velocity) at four representative distances (30, 100, 200, and 300 Mpc). (Fig 1. from Andreoni et al. 2022)

—> Impact of ToOs on other transient science: 1% - 3% Andreoni et al 2024

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