PHD PROJECTS IN THE ANALYSIS OF GRAVITATIONAL WAVE DATA

VIRGO EXPERIMENT – LIGO-VIRGO COLLABORATION

In this initial era of gravitational-wave astrophysics, searches for merging binaries are producing a wealth of results on the intrinsic properties of these sources, such as masses and spins, thanks to their well-understood theoretical models and their clearly recognizable waveforms. The studies on the different phases of the merger send a powerful message, that a significant part of the physics of the coalescence process can be recovered by a careful analysis of the time-frequency map.

However, compact binary coalescences (CBC) may display a very large variety of signal features such as higher order modes, high mass ratios, misaligned spins, eccentric orbits, which are difficult to detect and extract from the recorded signals. The challenge of an accurate reconstruction is especially important for the merger phase and the ringdown phase, which contain detailed information about important source-specific physical processes. See figure 1 from the "Catalog paper" (`https://arxiv.org/abs/1811.12907`) to appreciate visually the complexity of the time-frequency maps:

Now, the increased sensitivity of the interferometers of the LIGO-Virgo Collaboration (LVC), which have started their third joint observing run (03) on April 1st 2019 and shall continue taking data till the end of March 2020, is expected to expand our perspective on these phenomena. The increased sensitivity shall bring about a larger number of events, and shall allow an extended observation of the signal in the time-frequency map: comparing the current spectral sensitivity (May 2019) with the sensitivity at the time of the first detection, one should expect roughly a doubling of the observable inspiral time for an event like GW150914 (approximately 0.20 s instead of about 0.08 s).

The detection and reconstruction of CBC events is carried out by several analysis pipelines in the framework of the LVC, and the coherent WaveBurst (cWB) pipeline is one of them. Unlike other pipelines, cWB does not use a template bank (a large set of predicted waveforms that span the parameter space), and the event reconstruction is based on the patterns that populate the time-frequency map. This approach is both a liability and a strength of cWB. It is clearly a liability, because it gives up some prior knowledge that other pipelines use to set up optimal matched filters. However, it is an important strength in the search of yet unmodeled physics, where matched filters fail or simply do not exist.

The PhD projects currently offered in Trieste are related to cWB and specifically to the problems of feature extraction from the time-frequency map. In the past there have been attempts to attack the problem in a systematic way, as in the case of the WaveGraph algorithm, which searches for connected pixels in the time-frequency map with graph-theoretic techniques

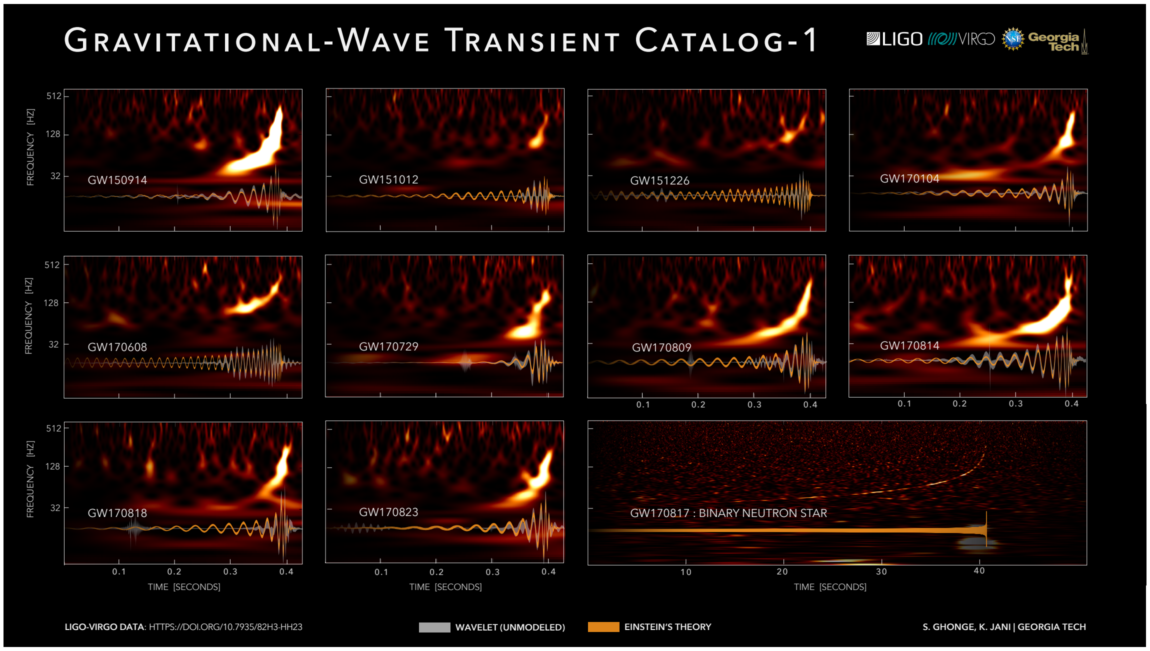

FIGURE 1. The reconstructed GW signals and the time-frequency maps listed in "GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs" (`https://arxiv.org/abs/1811.12907`).

(see, e.g. `https://arxiv.org/pdf/1805.04023.pdf`). The topics shall include a review of the algorithms for constructing the time-frequency map and compare their performances, their strengths and their weaknesses, a reconsideration of the physical constraints that put limits on the topology of pixel graphs in the time-frequency maps, and the extension of our analysis to include the topology of pixel graphs for GW's from supernova explosions.

List of basic references.

- The complete description of the cWB pipeline is publicly available at the address `https://gwburst.gitlab.io/post/2019-04-12-first_cwb_public_release/`
- A series of papers that describe the algorithms used in the pipeline:
  - S. Klimenko and G. Mitselmakher, A wavelet method for detection of gravitational wave bursts, Class. Quantum Grav. 21 S1819-S1830 (2004)
  - S. Klimenko et al., Constraint Likelihood analysis for a network of gravitational wave detectors, Phys. Rev. D 72, 122002 (2005)
  - V. Necula et al., Transient analysis with fast Wilson-Daubechies time-frequency transform, J. Phys.: Conf. Ser. 363, 01203 (2012)

  - S. Klimenko, G. Vedovato, M. Drago, F. Salemi, V. Tiwari, G.A. Prodi, C. Lazzaro, K. Ackley, S. Tiwari, C.F. Da Silva, and G. Mitselmakher, Method for detection and reconstruction of gravitational wave transients with networks of advanced detectors, Phys. Rev. D 93, 042004 (2016)
- Description of one competing pipeline (BayesWave)
  - N.J. Cornish and T. B. Littenberg, Bayeswave: Bayesian inference for gravitational wave bursts and instrument glitches, Class. Quantum Grav. 32, 135012 (2015)
  - T. B. Littenberg and N.J. Cornish, Bayesian inference for spectral estimation of gravitational wave detector noise, Phys. Rev. D 91, 084034 (2015)
- Description of a competing representation in the time-frequency plane:
  - S Chatterji, L Blackburn, G Martin and E Katsavounidis, Multiresolution techniques for the detection of gravitational-wave bursts, Class. Quantum Grav. 21 S1809–S1818 (2004)
- Link to the publicly released pipelines (including cWB):
  - `https://www.gw-openscience.org/software/`

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