# Prospective nationale en physique nucléaire, physique des particules et astroparticules

## Contribution au GT04 – Physique des astroparticules

## Real time gravitational waves astronomy

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### Motivations

Gravitational waves are produced by accelerated masses. This means that the most powerful and visible gravitational waves are produced during the most violent transient phenomena (and vice-versa). Such events, like the merger of two compact objects, lead to the release of a large amount of energy in a short time. They can be associated with a variety of signatures besides GW - electromagnetic signals or high energy particles – with diverse timescales, lasting from seconds to weeks.

The scientific results of the associated observations of GW170817 have demonstrated the high scientific return of such multi-messenger detection. But, in order not to miss the possible associated counterparts, the GW source should be detected as soon as possible, and possibly before the event. This is why a robust program of real-time detection of GW – or real time GW astronomy – needs to be pursued.

### Real time GW astronomy

The oversimplified description of real time (RT) GW astronomy is to take detector data, run some algorithms to find events and publish alerts to enable multi-messenger astronomy (see the multi-messenger contribution).

The outcome is not direct answers to scientific questions, like what is the value of the Hubble constant (see contribution on cosmology). RT GW astronomy is more a discovery process that enables getting these answers. It is also an open-minded process since some of the searches target the observation of an excess of energy, without a predefined model, or with very loose assumption on the rate of one class of events, as proved to be useful to establish the population of heavy stellar black holes during the O1 and O2 data taking runs of LIGO and then Virgo.

### Preliminary steps in RT GW astronomy

The goal of the RT GW astronomy is to detect as soon as possibly an event. Therefore, RT GW astronomy needs not only sensitive detectors but also calibrated data produced with very low latency. Currently, LIGO and Virgo produce h(t) with a latency of 10 to 20 seconds. Reducing this will require improving the whole chain, from the data acquisition system, h(t) reconstruction, to data distribution, without compromising the reliability of the h(t) stream or the data quality information. This is one of the challenges that will be addressed with new developments on calibration (see the calibration contribution to GT08).

**Core of the RT GW astronomy activities**

RT GW detection could be based on algorithms assuming un-modeled or predicted signals. Searches for un-modeled sources use excess power detection and are not going to be further developed here (see the supernova contribution for some discussion).

Modelled sources searched are usually compact binary coalescences (CBC). The search is performed by doing matched filtering using template banks with of the order of a million of elements to properly cover the parameter space.

One of the key features of these sources is that we observe them before the final merger. This means that, provided that the sensitivity of the detectors improves at low frequency as well as the algorithms and data analysis pipelines, we could detect them before the actual merger of the binary system. This information could be used to send pre-alerts with the ultimate goal of pointing telescopes that could observe the electromagnetic counterpart of the merger.
An even more challenging goal would be to tune in real time the sensitivity of the detector as the signal sweeps up the frequency band, in order to collect more information on the high frequency part. The work here would be to improve the pipelines and also to study the cost/benefit of the detector tuning.
In the long run, the prediction of the time and localization of the merger of two compact objects could benefit from LISA observations, since the time needed to go from the LISA bandwidth to the ground detector bandwidth will not be too long for heavy stellar black holes, offering accurate tests and reduced search areas for a hypothetical counterpart.

Another scientific question to be addressed is the parameter space used for these searches. There are first the usual questions: should we search for objects lighter than the usual 1 solar mass cut? Should we consider system with higher spins? In addition, the expected low frequency improvement of the 2.5 or 3G detectors will increase significantly the size of the template bank, because of the longer time spent in the detector bandwidth and the need to coherently integrate the phase of the signal during this time. The sensitivity increase means also that we can access sources at significant redshift (LIGO-Virgo have already reported a candidate at a redshift close to 1). This redshift directly applies to the observed parameters and is another input when deciding on the parameter space to search.
Overall, these questions translate into computing/algorithmic challenges (many millions of templates to search or different strategies), but also a scientific question to be addressed: when doing the search, should we put the same weight on all templates or give priority to some of them that are more likely to capture the not (yet) so well-known astrophysical source population?

Real-time GW astronomy usually has two steps. First the detection of candidates with some initial parameters estimation, sky localization, currently done in less than a minute. Then a more refined estimation of the parameters that could take many hours. One of the goals of RT GW astronomy would be to reduce the overall latency and develop parameter estimation tools providing the best results as soon as possible.

An incidental but important question is how to assess in an automated and reliable mode the data quality for the performed searches. Detectors will never be perfect and will always be sensitive to glitches that may fake signals. How do we make the best use of data quality information that must be produced in real time in a framework of multiple detectors with different sensitivities and not perfect duty cycle analysis? Strategies need to be developed and need to be more sophisticated than just using or ignoring a data stream.

It's worth noting that online GW searches are not disconnected from the offline searches that are used to produce official catalogues. Improvement in one type of searches benefit to the other one.

**Products of the RT GW astronomy and issues**

The primary deliverables of RT GW astronomy are reliable alerts. The current paradigm is to release as soon as possible reliable candidates. Multiples pipelines are running parallel searches, leading to very different questions that will need to be investigated:

- How do we reduce the latency of the alert system and what should be the target?
- How do we handle the aggregation of results from pipelines?
- 3G detectors should offer more than 3 orders of magnitude in the event rate compared to now. How do we handle this rate, the pileup of events, and highlight the most interesting events?
- Should we have different policies for subthreshold events that will be produced with an even higher rate?
- How is the science done in an open model and what is the return for people developing the detectors and the GW detection pipelines?