Random projections for the reduction of gravitational wave template banks

Eric Chassande-Mottin (APC, CNRS/Univ de Paris)
Laurent Daudet (LighOn, Prof on leave Univ de Paris)

Candidate intern: Thomas Sainrat (CentraleSupélec)

Motivations

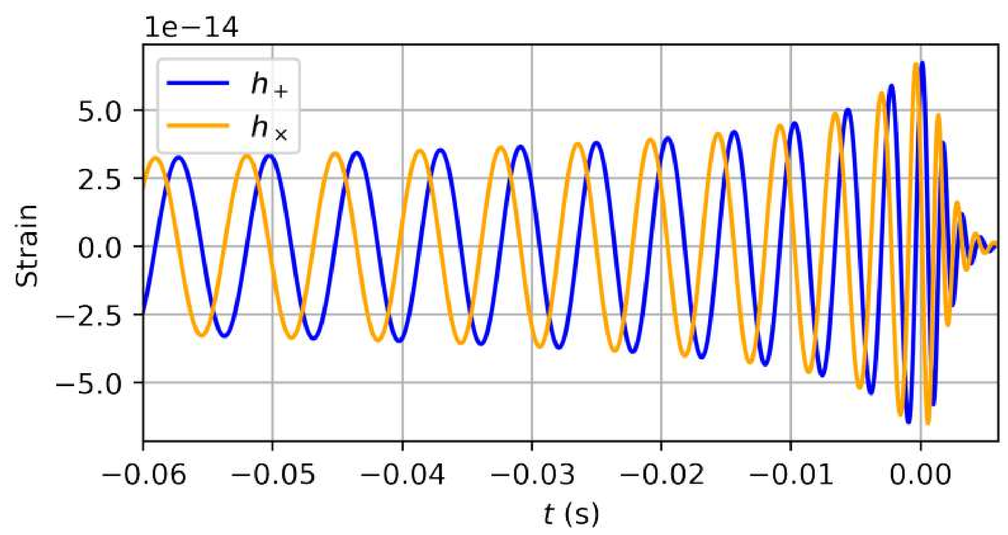
The **direct observation of gravitational waves (GW) by the LIGO and Virgo detectors** is one of the breakthrough discoveries of the beginning of the 21st century [1]. This **new astronomy** opens new opportunities, specifically for the study of compact stars such as neutron stars and black holes.



Aerial view of the Virgo detector in Italy

Binaries of compact stars radiate away potential energy through gravitational waves, leading to the decay of their orbital trajectory and that eventually concludes with the merger of the binary components. A **strong burst of GW is emitted during the last seconds of the binary in-spiral**, which can be detected and measured by interferometric detectors such as LIGO and Virgo.

The GW signal follows a specific waveform morphology that can be predicted with good accuracy by **physical models** deduced from the resolution of the source orbital dynamics. The exact phase evolution of the signal depends on the characteristics of the component objects that compose the binary system (such as the masses and spins). **Figure 1 provides an example of one such waveform** (the two wave polarizations h_+ and $h_\times$ are shown).



Example of the gravitational wave signature expected from the mergers of two compact stars

Problem statement

Matched filtering techniques [2] are very effective for searching for compact binary mergers in the LIGO and Virgo data (dominated by instrumental noise). The data are correlated with **a set of templates (called *bank*)** that provide a discrete sampling covering the entire parameter space defined by the binary component masses and spins. **Fully covering template banks typically include 500,000 waveforms.** Correlating with this many templates thus represents a **large computing cost.**

This provides strong motivations to **reduce the template bank**. Because of the large size of the data, popular techniques such as **PCA are prohibitive in term of memory and CPU usage**.

*The goal of this work is to investigate ways to reduce the gravitational-wave template banks through an alternative technique called **random projections [3] and to perform this reduction efficiently using Optical Processing Units [4]**.*

Project Implementation

Random projections have been investigated [5] in the context of GW astronomy with a reduction by two orders of magnitude (from a **~20,000 template bank to 150 basis elements**). This study has been done for current (2nd generation) GW detectors.

We will conduct a similar study with two innovations:

- **Aim at future (3rd generation) GW detectors** such as the Einstein Telescope in EU and Cosmic Explorer in the US [6]. This is the relevant application scenario for this technique as the exhaustive coverage of the parameter space used so far will probably not be sustainable
- Test the computation of the random projection **using Optical Processing Units (OPU) provided by Light-On.** OPUs have the potential to drastically decrease computation time and memory, as well as power consumption [4].

References

[1] B. P. Abbott et al., Phys. Rev. Lett., v 116, pp. 061102, 2016.
[2] B. P. Abbott et al. Class. Quantum Grav. 37 055002, 2020.
[3] PG Martinsson, V Rokhlin, and M Tygert. Appl. Comput. Harm. Anal., 30(1):47 – 68, 2011.
[4] Charles Brossollet et al., LightOn Proceedings IEEE Hot Chips 33, 2021
[5] Reza, Amit et al., arXiv:2101.03226, 2021
[6] Einstein telescope http://www.et-gw.eu and Cosmic Explorer https://cosmicexplorer.org/

This work is supported by diiP, IdEx Université de Paris, ANR-18-IDEX-0001