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FAST TRIGGER ALGORITHMS FOR BINARY COALESCENCES.

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Abstract

The construction of two broad bandwidth gravitational antennae (Virgo and Ligo) is now started. Such interferometric detectors will do a constant survey of the sky. It results in a huge amount of continuously recorded data, inconsistent with the need for a flexible and tunable off-line signal search. This requires on line triggers, selecting "gravitational wave signal candidates".

This work is a first attempt to study some simple on-line trigger algorithms for the futur interferometric Virgo detector, selecting candidates of gravitational wave signal induced by binary coalescences. Firstly, we point out the conditions on-line triggers must obey. Then, we see that, used as an on-line trigger, the standard method of matched-filtering has some problems to fulfil these conditions. In a third step, we propose and study possible trigger algorithms, focusing our attention on their efficiency, their ability to reduce the amount of data, their robustness in front of the first post-Newtonian term and, of course, their processing speed.

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1 Introduction

Some 70 years ago, physicists agreed on the fact that gravitation can propagate and that "those tiny space-time deformations propagates with velocity of light" [1]. Some 30 years ago [2] [3], people began to examine the possibility of detecting gravitational waves coming from cosmic events like supernovae. Some 15 years ago, a new and somewhat more interesting source of gravitational waves was proposed: binary coalescence [4] [5]. For now, three short-period binary pulsars have been observed (PSR1913+16, PSR1534+12 and PSR2127+11C), enforcing the idea that those systems are sources of gravitational waves.

The french-italian Virgo experiment, as well as the american one (Ligo), are now approved for construction. These projects expect to have working detectors in the coming years, aiming a sensitivity of some $10^{-23} \text{ Hz}^{-1/2}$ above 100 Hz [6] [7]. This could open a new window on the detection of the presently most promising candidates: binary coalescences.

In this article, we will study [8] how to perform on-line selection of "binary coalescence signal candidates" in the data produced by the Virgo experiment.

1.1 Why a data selection ?

A large base-line interferometric detector like Virgo is a complex system with many feed-back loops. In order to validate gravitational wave signals, many signals and parameters will have to be monitored and recorded. With a bandwidth going up to some kiloHertz, the sampling rate may be as high as 20 kHz, which could gives several hundreds KBytes of data (signal plus monitoring) per seconde [7]. Integrated over a year, the amount of data will be huge: some TeraBytes per year (many times the annual data production of CERN particle physics detectors on LEP accelerator). Virgo reveals thus in the field of data acquisition some analogy with high energy particle physics experiments.

The gravitational signal search will not be a straight forward operation and will require several off-line data processing with various search algorithms, recalibration or check of algorithm efficiency. The size of this continuously growing data sample would make this analysis very difficult and quite unmanageable. Some help could come from simple, robust, fast and efficient trigger algorithms, which would reduce the amount of data by one or two orders of magnitude, by selecting gravitational waves candidates on special tapes from the plain raw data stream.

1.2 General features of trigger algorithms

On-line selection algorithms will, a priori, use a standard way of selection, comparing values they calculate to a predefined threshold. Each time, the value is over the threshold, they must trigger, that means they must save a piece of raw data, on which off-line algorithms will perform more sophisticated searches. Such on-line triggers must meet five conditions:

1. **Threshold efficiency:** It must select all possible gravitational wave candidates that could be seen by any off-line search.
2. **Rejection:** It has to reduce by a sufficient factor (more than 10) the amount of data.
3. **Signal pattern efficiency:** it must have enough robustness against the mismatch of the signal form, that means it has to be sensitive enough to a relative large spectrum of signals.
4. **Simplicity:** It must be simple enough, in its conception and in the technics it uses, to permit reruns of analysis, thus verifying its efficiency.
5. **Speed:** It has to be fast enough to run on-line.

1.3 Binary coalescences

A binary coalescence is the end stage of the inspiraling of two massive objects (neutron stars or black holes), radiating gravitational waves with increasing frequency and increasing amplitude (see figure 1). In a special frame "attached to the wave" (TT frame), the gravitational wave of binaries can be expressed with two polarisations [9]:

$$\begin{aligned} h_+ &= 0.5 \times (1 + \cos^2 \beta) h(t) \cos(\phi(t)) \\ h_\times &= \cos \beta h(t) \sin(\phi(t)) \end{aligned} \tag{1.1}$$

where β is the angle between the sight line and the rotation axis of the binary system. To get the expression of amplitude $h(t)$ and phase $\phi(t)$, one can have a perturbative approach like the one called post-newtonian development [10] [11]. At zero order of this development (newtonian approximation) $h(t)$ and $\phi(t)$ are given by the following expressions:

$$h(t) = 1.19 \cdot 10^{-22} \frac{K}{d} \nu(t)^{2/3} \tag{1.2}$$

and

$$\phi(t) = \phi_o - \frac{8}{5} 2\pi \nu_o \tau \left(1 - \frac{t}{\tau}\right)^{5/8} \quad (1.3)$$

with

$$\nu(t) = \left[\nu_o^{-8/3} - 1.53 \cdot 10^{-6} K t \right]^{-3/8} \text{ Hz} \quad (1.4)$$

and

$$\tau = 6.53 \cdot 10^5 \frac{\nu_o^{-8/3}}{K} \text{ sec.} \quad (1.5)$$

where ϕ_o and ν_o are the phase and the frequency of the gravitational wave at $t=0$, τ is the duration of the coalescence, d is the distance between the source and the observer (in Mpc units), $\nu(t)$ is the frequency of the gravitational wave (in Hertz units) and $K = \mu M^{2/3}$ (in solar mass units) is a mass parameter depending on the reduced mass $\mu = m_1 m_2 / (m_1 + m_2)$ and on the total mass $M = m_1 + m_2$ of the binary system.

At the end of coalescence inspiraling, when stars have high velocities, the first post-newtonian terms of the development in term of v/c cannot be neglected any more. The corrections to the newtonian's one (expressions 1.2 and 1.3) are respectively:

$$PN1_h = 4.04 \cdot 10^{-24} \frac{1}{d} \left(1 - 0.514 \frac{\mu}{M}\right) \mu^{-1} \nu(t)^{4/3} \quad (1.6)$$

$$PN1_\phi = 1.5 \cdot 10^4 \left(1 + 1.24 \frac{\mu}{M}\right) \mu^{-1} \nu(t)^{-1} \quad (1.7)$$

For two typical neutron star masses of $1.4 M_o$ ($K=1.4$) at 100 Mpc, 2 seconds before the final collision, the frequency is approximately 100 Hz and the amplitude is about $h = 3.6 \cdot 10^{-23}$ in the direction of the binary rotation axis.

Within that distance of 100 Mpc, few binary coalescence per year is, for now, the usual expected observation probability [12] [13].

2 Detection criteria and sensitivity limit.

Before any study of on-line triggers, we have to define the way of choosing their working threshold, that means the choice of a detection criteria on the search of binary coalescence signal. This threshold is tied to the distance of the source, because binary coalescence signal amplitude $h(t)$ is inversely proportional to the distance d .

The more stringent of the five conditions on on-line triggers is that: "It must not miss a gravitational wave signal detectable by off-line search". It means that the threshold used by any on-line trigger algorithm must at least permit to reach the

distance d_{max} defined as the maximal distance of a binary coalescence detectable in off-line search.

To see what will be the exact correspondance between the signal to noise ratio and the distance of the source, let us calculate the optimal signal to noise ratio [14] defined by:

$$\rho^2 = \int_0^\infty \frac{2 |\tilde{h}(\nu)|^2}{|\tilde{b}(\nu)|^2} d\nu \quad (2.1)$$

where $\tilde{h}(\nu)$ is the Fourier transform of the binary coalescence signal and $|\tilde{b}(\nu)|^2$ is the spectral density of noise. We need to know the expressions of spectral noise $|\tilde{b}(\nu)|^2$ and of Fourier transform $\tilde{h}(\nu)$.

We assume for this calculation that the sensitivity is dominated by two noises: pendular thermal noise and a flat noise which can be either the shot noise (used here) or the mirror thermal noise below first mirror normal mode. Given the Virgo specifications, we use, for total spectral noise, the following parametrization:

$$|\tilde{b}(\nu)|^2 = \left(\frac{a_t}{\nu^2}\right)^2 + a_s^2 \text{ Hz}^{-1} \quad (2.2)$$

where the first term a_t (here $a_t = 2.10^{-19}$) represents the pendular thermal noise in a simple model of damped harmonic oscillator and where the second term a_s (here $a_s = 2.10^{-23}$) represents the shot-noise.

To calculate the Fourier transform $\tilde{h}(\nu)$ we use the first order approximation [11]:

$$|\tilde{h}(\nu)|^2 = \frac{1}{4} \frac{h^2(t)}{\dot{\nu}(t)} \text{ Hz}^{-2}$$

where $h(t)$ is the amplitude of the h_+ polarisation when the gravitational wave is optimally oriented with respect to the detector arms and where $\dot{\nu}(t)$ is the time derivative of $\nu(t)$. Using 1.2 and knowing that:

$$\frac{\dot{\nu}(t)}{\nu(t)} = 0.1248 K \nu^{8/3}$$

which calculate:

$$|\tilde{h}(\nu)|^2 = 2.8 \cdot 10^{-44} \frac{K}{d^2} \nu^{-7/3} \text{ Hz}^{-2} \quad (2.3)$$

With those expressions of noise and signal and using numerical integration, the correspondance between the signal to noise ratio ρ and the source distance d is:

$$\rho(d) = \frac{270\sqrt{K}}{d} \quad (2.4)$$

Over one year, let $n_b(\rho)$ be the number of events above the threshold $\rho(d)$ due to false alarms and let $n_s(\rho)$ be the number of true events above $\rho(d)$, we are waiting for. We will say that a gravitational wave signal has been observed when we have a three sigma effect or:

$$n_s(\rho) \geq 3\sqrt{n_b(\rho)} \quad (2.5)$$

Let us first calculate $n_b(\rho)$. If we suppose that the detector noise has a gaussian distribution, we can write:

$$n_b(\rho) = N_{try} \frac{3600 \times 24 \times 365}{\Delta t_o} \int_{\rho}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{\sigma^2}\right) dx$$

where the normalising factor is the total number of values calculated by the algorithm in one year, Δt_o is the output rate of the trigger algorithm and σ is the standard width of the gaussian noise distribution. The choice of Δt_o is tuned by the width of the autocorrelation pic of a binary coalescence signal and N_{try} is the number of samples a matched-filtering algorithm would need in searching for the signal at newtonian approximation. We find $\Delta t_o \approx 5 \cdot 10^{-3}$ second and we typically set $N_{try} = 500$ (see paragraph 4).

Now, if we suppose a uniform distribution for the binary coalescence sources and if we take an observation probability of 10 coalescences per year in a sphere of 100Mpc radius, we can calculate the value $n_s(\rho)$. Using 2.4, we get:

$$n_s(\rho) = 10 \left(\frac{270\sqrt{K}}{100\rho} \right)^3 \quad (2.6)$$

Solving numerically 2.5 in case of equality and taking into account the smearing effect of signal distribution [8], we find $\rho_o = 7.9\sigma$. The corresponding maximal distance is (from 2.4):

$$d_{max} = (35 \text{ Mpc}) \sqrt{\frac{K}{1.4}} \quad (2.7)$$

This result is weakly sensitive to the value of Δt_o as shown by figure 2 for three values of the mass parameter K. But this maximal distance is function of the noise parameters of equation 2.2. Figure 3 shows d_{max} versus these two parameters a_t (pendular thermal noise) and a_s (shot-noise or any "flat noise").

3 Time of visibility of a coalescence signal.

Each time the trigger detects a signal above the threshold, a piece of raw data is recorded on the "trigger tapes". The time duration T of this data sample is limited

by the times t_1 and t_2 , where:

- t_1 : is such that optimal signal to noise ratio integrated between $t = -\infty$ and t_1 is less then one. It means that we suppose that data before t_1 are useless for any sophisticated signal search.
- t_2 : is the suspected final collision time of the coalescence (first value of the algorithm output which is under the threshold after triggering).

Of course safety margins (some seconds) are added at both ends.

In newtonian approximation, time of coalescence Δt is related to its fręquency f_0 by the relation:

$$\Delta t = 6.53 \cdot 10^5 \frac{f_0^{-8/3}}{K} \text{ sec.} \quad (3.1)$$

From equation 2.1, a numerical calculation gives the following parametrization:

$$\rho(1 \rightarrow f_0) \approx (1.175 - 0.17 f_0) \sqrt{\frac{K}{1.4}} \frac{10}{d} = 1 \quad (3.2)$$

where $\rho(1 \rightarrow f_0)$ is the optimal signal to noise ratio integrated between 1 Hz and f_0 . Equations 3.1 and 3.2 give for the time duration of raw data recorded the following approximation :

$$T = \frac{5790}{K} \left(\sqrt{\frac{1.4}{K}} \frac{d}{10} + 1.175 \right)^{-8/3} \text{ sec.} \quad (3.3)$$

Let's keep in mind that those values of maximal distance and time of visibility are calculated in the noise environment defined in equation 2.2.

4 Matched-Filtering. Advantages and drawbacks.

To extract from the noise a signal of known form, the best tool is provided by matched-filtering technics [15] [16], which correlates the signal received $f(t) = h(t) + b(t)$ with the expected form of the signal $h(t)$ normalised to the noise spectral density $\tilde{b}(\nu)$. We will name $M(t)$ such a template. The result of the correlation over a time window of width T is then:

$$C(t_0) = \int_0^T M(t).f(t - t_0) dt$$

This time window is moved over data with a time step Δt_o as large as the auto-correlation pic of the signal searched . Matched-filtering can give the optimal signal to noise ratio and will be used in off-line analysis, as many authors have already suggested [17] [18]. Nevertheless, binary coalescence signal is not exactly known and

matched-filtering has therefore to face two major problems, in order to be used as an on-line trigger.

Unknown mass parameter:

The value of the mass parameter K of the binary coalescence is unknown. This implies that we look at the signal correlation with different templates $M(K,t)$. Figure 4 shows the result of the correlation between a signal $h(t)$ of mass parameter K_o and a template $M(K,t)$ of mass parameter K . It shows that, to maintain a sufficiently good signal to noise ratio, precision on K is needed. About 500 templates $M(K,t)$ are thus requested to search for a coalescence signal between $K=1$ and $K=4$. The result is a quite long calculation time: on a UNIX station HP730 using 500 templates $M(K,t)$ and a time step of $\Delta t_o = 5.10^{-3}$ second, it took approximately 1300 seconds to analyse 1 second of data!

Post-newtonian terms:

An even more important drawback of matched-filtering method is that, even if the value of K is known, the form of the template can be mismatched because of the existence of post-Newtonian terms. The tiny contribution of the first post-newtonian term (1.7) accumulates in the phase of the signal. It means that the right sample $M(K_o, t)$ will mismatch the signal $h(t)$ after some cycles. A more sophisticated description of this effect can be found in [19]. Figure 5 shows, versus frequency, the time duration taken for the template $M(K_o, t)$ to be in phase opposition with $h(t)$ because of first post-newtonian term effect. At 10 Hz, when coalescence time left is about 1000 seconds, this time duration is about 3 seconds only.

This cumulative effect of little terms implies to know precisely, with many post-newtonian terms, what is the signal shape. This implies other mass parameters and the use of even more samples for the matched-filter. This means more calculation time.

Taking in account those two problems, we see that using matched-filtering as an on-line trigger would be a very heavy task. In fact, computing time is a problem which could be solved at some price by doing parallel processing [20] or by using dedicated hardware. But the major problem is the complexity introduced by such methods. To do any efficiency or robustness checks, we will need all the templates used by the trigger. This makes the off-line analysis quite unmanageable.

Consequently, we will look for simple algorithms, not so good in their signal to noise ratio performance but aiming at respecting the conditions defined in paragraph 1.2.

5 Study of algorithms for on-line trigger.

5.1 Simulation program

To study on-line triggers, we used a simulation program, named SIESTA (Simulation of Interferometric dEtector Sensitive to graviTational wAves), which is presently developped at LAPP, in Annecy [21]. This program has two faces: to simulate gravitational waves signals we are waiting for and to simulate the gravitational antenna and all its possible noises, taking in account, as precisely as possible, the different active parts of the interferometric detector. It will be useful in mixing simulated signals with real or simulated data in order to study the capabilities and efficiencies of on-line and off-line algorithms.

This program is already able to work on different modes, performing optical propagation of the laser beam, including mirrors and cavities defects, or simulating data produced by the interferometer as a tool for data analysis. For now, the "data mode" simulates the moving parts of the interferometer, computes the "dark fringe" and output the simulated data (ADC and data acquisition included).

Shot noise and pendular thermal noise are the basic noises of the Virgo detector in the frequency range of binary coalescence detection (10Hz to 1000Hz). In our study, the simulation will take only these two noises into account at a level given by the parameter values of expression 2.2. Figure 6 shows the corresponding frequency spectrum (with a 10kHz sampling rate). Figure 7 shows versus time a simulated signal of coalescence at 1 Mpc as seen by Virgo in this noise environment.

A special part of SIESTA is devoted to the simulation of signals: binary coalescences at the first post-Newtonian order and periodic signals of pulsars, including Doppler effects.

Given the optimal signal to noise ratio 2.1 , for a typical coalescence signal and a typical noise environment, most of the useful signal is expected in the range 50 Hz to 300 Hz. Therefore the sampling rate used in this analysis is 1 kHz.

5.2 Gabor analysis

A binary coalescence signal is a pseudo-periodic one with increasing frequency and increasing amplitude. A first method to detect such a signal consists in doing a "local Fourier transform" of data over a time window located at time t_0 , inside which the signal can be considered as almost periodic [22]. Then, using some templates (10 to 20 values of K) of theoretical frequencies $f(K, t)$, we can look for the signal

pic in each local FFT (Fast Fourier Transform) and integrate it along all the time duration of the coalescence, from the "begin-of-analysis" frequency $f_0 = 50$ Hz till the "end-of-analysis" frequency $f_{max} = 250$ Hz, which can be considered as the very end frequency at which newtonian approximation used by the samples $f(K, t)$ is available. The value calculated at time t_0 is:

$$S(t_0) = \max_K \left(\sum \frac{J_i(K)}{\sigma_i} \right)$$

where J_i is the integral of the frequency spectrum (local FFT) around the supposed signal pic and σ_i is the spectral noise fluctuations standard width at the frequency we are observing. A byproduct of this computation is the K value which gives the maximal sum $S(t_0)$.

Figure 8 shows, as a function of time, $S(t_0)$ and K values for a source located at 10 Mpc with $K=1.4$. A clean signal is here observed at the time of coalescence. But this algorithm has a problem because $S(t_0)$ is not always proportional to $1/d$ like we would naively expect. It has a non-linear behaviour for small signals. This non-linearity comes from the fact that we use modulus of Fourier transform and integrate on it. This introduce a threshold effect, because the true signal is quadratically mixed with the noise. The only way to have a sufficient reduction rate of data is then to work with a threshold corresponding to a distance of about 60% of the maximal distance.

Gabor analysis, despite its non-linearity, is fast enough to run on line and showed a quite good robustness against the first post-newtonian term (about 20% of signal amplitude reduction at the output of algorithm, when first post-newtonian term is present in the signal and when analysis is done at newtonian order only). This robustness comes from the fact that we do not take into account the information coming from the phase of Fourier transform.

5.3 Wavelet analysis

The principle of the method is approximately the same as before: in a time window, located at time t_0 , data are analysed. But, analysis is done with wavelet functions. instead of cosinus and sinus functions. With wavelets, we can adapte the width of the time window to the frequency examined. This allows us to do a spectral analysis very locally in time [24]. We have chosen for simplicity the Morlet wavelet function, defined by:

$$\psi_m(t) = \exp(2i\pi\nu_o t) \exp(-t^2/2)$$

with $2\pi\nu_o \geq 5$ to have a sufficient number of oscillations in the width of the exponential part. This wavelet function is approximatively acceptable to be a mother-function for wavelet analysis [23]. For each time b , different scales a are examined. The analysing wavelet is: $\psi_{ab}(t) = \psi_m(\frac{t-b}{a})$ and the frequencies examined are $\nu = \nu_o/a$. The result of wavelet transform is a set of wavelet coefficients:

$$W_{ab} = \int_{-\infty}^{\infty} \psi_{ab}^*(t) f(t) dt$$

Like Fourier coefficients, W_{ab} is the scalar product between the wavelet function and the function $f(t)$ analysed. Figure 9 shows the whole set of wavelet coefficient modulus $|W_{ab}|$, called a scalogram, with time parameter b inside the analysing time window limits and a between ν_o/f_{max} and ν_o/f_0 , where f_0 and f_{max} are the begin-of-analysis and end-of-analysis frequencies. This time-frequency analysis shows here the signal ridge $\nu_g(b)$ of a source located at 10 Mpc.

Once obtained the scalogram, we can use a set of theoretical ridges $\nu_{th}(K, b)$ and get the values $S(t_o)$ in summing the wavelet coefficient modules $|W_{ab}|$ along each theoretical ridge :

$$S(t_o) = \max_K \left(\sum_{\text{ridge } \nu_{th}(K, b)} |W_{ab}| \right)$$

This method still introduce a threshold effect and again it can reduce the amount of data by a sufficient factor only when working at about 60% of the maximal distance.

Wavelets analysis, despite its non-linearity, was also able to work on-line and showed a quite good robustness against the first post-Newtonian term (again a signal amplitude reduction of about 20%).

5.4 Resampling

First, we tried to analyse the signal with a "local FFT" method, using time windows of fixed width (Gabor analysis). Then, we tried to improve the method in adapting the size of time windows to the frequency examined (Wavelet analysis). The best we can do is to adapt the size of time window to the frequency of the binary coalescence signal. The way we used consists in resampling the data at a frequency increasing like the one of the signal. The signal of binary coalescence given by 1.1 and 1.3 can be written: $h_+(t) = h(t)\cos(2\pi f_0\chi(t))$ and will appear in resampled data as a periodic signal [25].

As a result, resampling is equivalent to replace the variable t by the new variable $\chi(t)$. Knowing that $\chi(t) = 8/5\tau(1 - t/\tau)^{5/8}$, where τ is the time duration of the

coalescence, and keeping $d\chi = C^{te}$, we get the following resampling:

$$\begin{aligned} dt_n &= \left(1 - \frac{t_n}{\tau}\right)^{3/8} \\ t_{n+1} &= t_n + dt_n \end{aligned} \quad (5.1)$$

At each time t_n a h-value data is taken. Moreover, to reduce the noise, we take for h-value resampled data not only the h-value data picked up at t_n but the average of all h-value data located between t_{n-1} and t_n . A FFT of those resampled data will exhibit a signal pic at frequency f_0 .

To use such a method, some conditions have to be respected:

- The number N of data in the time window of analysis, after resampling, must be less than $\frac{16}{3}\tau f_0$. Otherwise, the frequency f_0 would be out of the FFT range, according to the Shannon theorem.
- The value of $d\chi$ must be less than $1/(2f_0)$. Otherwise, resampled data could be unlucky picked up only at each minimum of coalescence signal.

This algorithm searches the signal between 80 Hz and 250 Hz. Analysis is done at newtonian order. Figure 10 shows the result of a FFT made on resampled data, with a coalescence at 1 Mpc, when the time window, inside which resampling is made, is correctly set and when it is 0.1 second earlier or later. The value $S(t_0)$ is here defined by the maximal value found in the FFT of resampled data, in a frequency range corresponding to the mass parameter range where we are searching for the coalescence signal. Figures 11 shows $S(t_0)$ for a binary coalescence $K=1.4$ at 10 Mpc. Figure 12 shows the distance calibration of the resampling algorithm which is quite linear.

On 50 hours of simulated data, the threshold being set at the one corresponding to the maximal distance d_{max} , the result obtained is a data reduction rate of 90. This algorithm gives thus a quite good result.

It is fast enough. Using a UNIX station HP730, the resampling algorithm needs only 47 mn to analyse one hour of simulated data.

It has also a quite good robustness. A source simulated with first post-newtonian term and the resampling algorithm working at newtonian order, we find a decrease of about 20% of the signal amplitude at the output of the algorithm, with respect to what is obtained when the source is simulated at newtonian order and analysis done at newtonian order too. This gives good confidence in its robustness against post-newtonian terms in general.

Remark that we did not, in this algorithm, divided the signal received by its time varying amplitude. Therefore, the exact result of resampling is not a perfect periodic signal. It can be showed that, as long as we are concerned with frequencies less than 200 Hertz and a newtonian approximation, the result of this algorithm is not statistically changed by this approximation.

6 Conclusion

We have first described the need for on-line triggers in gravitational waves experiments like Virgo. By using the fact that on-line triggers should not bias off-line analysis, we have defined a criteria of detection and determined from it the threshold (or maximal distance d_{max}) that prevents any miss of coalescence signal. Then we have pointed out the problems of the matched-filtering method used as on-line trigger.

Using a simulation program, we have studied three possible simple algorithms, which revealed their abilities to work on-line and we have shown that at least one of them is able to reduce the amount of data by a factor 90 without missing detectable real signal. Each of the three algorithms have proved to be quite robust against the problem of first post-newtonian term (reduction of approximately 20% of the signal amplitude), giving good confidence in their robustness against post-newtonian terms in general.

Many improvements have still to be done on such on-line triggers, but we have demonstrated that on-line triggering on gravitational wave interferometric experiments is possible without huge or complex computing power.

In addition to their threshold difference, the three studied algorithms have different frequency range efficiency, triggering at different times. Therefore the use of the two first algorithms could help the decision coming from our "best" one.

Following this idea, a perspective for the futur is therefore to develop different simple algorithms with the aim of a parallel processing of them, which would allow a better on-line tagging of binary coalescence signals.

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Caption list:

Figure 1: Gravitational wave signal h_+ of a binary coalescence $K=1.4$ (two neutron stars of $1.4 M_\odot$ each) at 1Mpc. The orbit is supposed circular and the observer is supposed optimally located (right orientation and sight along the axis of the binary system).

Figure 2: Maximal distance d_{max} versus time step Δt_o for three different mass parameters: $K=1.4$ (two "standard" neutron stars), $K=3.77$ (one neutron star $m_1 = 1.4$ and one possible black hole $m_2 = 5$) and $K=36.8$ (two black holes $m_1 = 10$, $m_2 = 10$).

Figure 3: Maximal distance for binary system with $K=1.4$ versus the pendular thermal noise and a "flat noise" (here the shot noise). The two crossing dotted lines show the values of noise parameters corresponding to the noise used in this study.

Figure 4: Correlation function between a coalescence signal of mass parameter K_o and a coalescence signal of mass parameter K . Here is shown the maximum of the correlation pic versus the value of K .

Figure 5: Time duration to have a dephasing of π between coalescence signal at first post-newtonian order (PN1) and coalescence signal at newtonian order (PN0), versus the frequency of the gravitational wave signal.

Figure 6: Frequency spectrum in $Hz^{-1/2}$ units of simulated data, with thermal at low frequency and shot-noise at high frequency. This figure is an average over 10 windows of 8 secondes width.

Figure 7: Data output of the simulation: gravitational wave signal of a binary coalescence $K=1.4$ at 1Mpc is mixed with shot noise (little amplitude and high frequency) and pendular thermal noise (high amplitude and low frequency).

Figure 8: Top view: Values $S(t_0)$ calculated by the algorithm using Gabor analysis, when a signal of coalescence $K=1.4$ at 10 Mpc is included into simulated data. Bottom view: Keaped values of K corresponding to the values $S(t_0)$ and pointing out the value $K=1.4$ of the coalescence at time t_o of signal pic maximum.

Figure 9: Scalogramme of simulated data when a signal of coalescence at 10 Mpc (visible ridge) is included into the simulated data. Boxe sizes are proportional to the modulus of values $|W_{ab}|$.

Figure 10: Frequency spectrum of resampled data when a signal of coalescence at 1 Mpc is mixed with simulated noise. For three cases: (1) when analysis window is 0.1 second later than the signal, (2) when it is correctly placed, (3) when it is 0.1 second earlier.

Figure 11: Values $S(t_0)$ calculated by the algorithm when a coalescence signal $K=1.4$ at 10 Mpc is included into the simulated data.

Figure 12: Distance calibration of the values $S(t_0)$.

Figure 1

Ref. ¹

¹R. Flaminio, Astroparticle Physics, figure 1.

Figure 2

Ref. ²

²R. Flaminio, Astroparticle Physics, figure 2.

Figure 3

Ref ³

³R. Flaminio, Astroparticle Physics, figure 3.

Figure 4

Ref ⁴

⁴R. Flaminio, Astroparticle Physics, figure 4.

Figure 5

Ref ⁵

⁵R. Flaminio, *Astroparticle Physics*, figure 5.

Figure 6

Ref ⁶

⁶R. Flaminio, Astroparticle Physics, figure 6.

Figure 7

Ref ⁷

⁷R. Flaminio, Astroparticle Physics, figure 7.

Figure 8

Ref ⁸

⁸R. Flaminio, Astroparticle Physics, figure 8.

Figure 9

Ref ⁹

⁹R. Flaminio, *Astroparticle Physics*, figure 9.

Figure 10

Ref ¹⁰

¹⁰R. Flaminio, Astroparticle Physics, figure 10.

Figure 11

Ref ¹¹

¹¹R. Flaminio, *Astroparticle Physics*, figure 11.

Figure 12

Ref ¹²

¹²R. Flaminio, Astroparticle Physics, figure 12.