# Missed astrophysical signal in the GW150914 event

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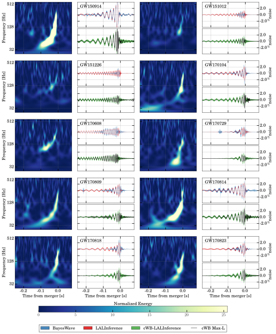
# Content

# Introduction: I





On the one hand, there is compelling evidence that we are in the presence of several detections of gravitational waves.
On the other hand, one can find concerns in publications questioning the nature of the detections.

How can we settle this issue ?

# Introduction: II

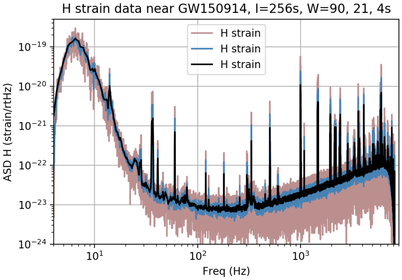
**New filtering strategy:** We present a new strategy for the pre-processing filtering of strains that circumvents difficulties in the standard procedures.

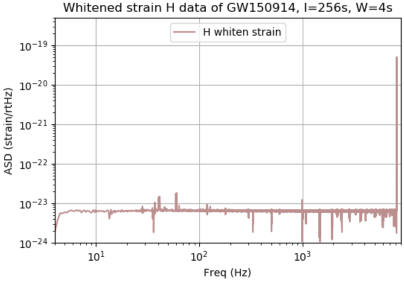
**New measure for common signal:** We show the results of applying a new measure for the detection of similar signals in both LIGO observatories for the GW150914 event.

**Identifying the nature of a gravitationa wave:** Using the new filtering techniques, and the new measure for the search of similar signals in two observatories, we show the presence of the spin 2 signature of the gravitational wave in the GW150914 event.

# New pre-processing filtering techniques for GW signals. I

**The whitening procedures used by LIGO**




On the left, amplitude spectral density of raw data from Hanford, in the range from 4 to 9000Hz, for the interval of 256s around the time of the event with 90s, 21s and 4s windows; where we have chosen the upper limit in excess of the cutoff at the Nyquist frequency, so that it can be observed. On the right, amplitude spectral density of the whitened strains for 256s intervals, and windows of 4s, as suggested in LIGO public python scripts, for Hanford data, with a normalization that preserves the units.

The whitening procedure is useful for the process of determining a detection; but it has some other disadvantages.

# New pre-processing filtering techniques for GW signals. II

**Filtering without whitening**

We present here a new approach for the pre-processing initial filtering based on finite impulse response (FIR) filters, in order to circumvent the effects of whitening and occasional use of infinite impulse response filters (IIR) use by the LIGO team.

Suppose that there is significant signals at low frequencies. In that case, the whitening procedure will wash away these physically interesting information of the observed data.

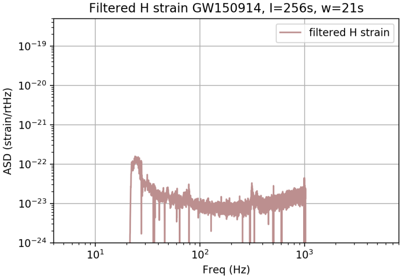
In our analysis we have applied:

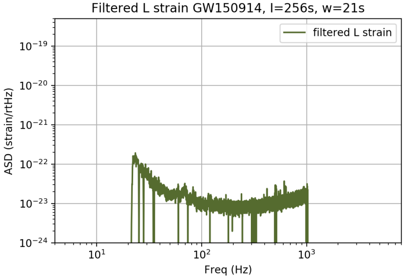
- an initial FIR bandpass filter from 22Hz to 1024Hz (to hide unphysical high and low frequency noise)
- narrow FIR stopband filters (to suppress the intrinsic noise of the instrument)

This is a minimum type of filtering that respects possible high an low frequency physical interesting information encoded in the observed data.

# New pre-processing filtering techniques for GW signals. III

## Strains after applying our pre-processing filtering method

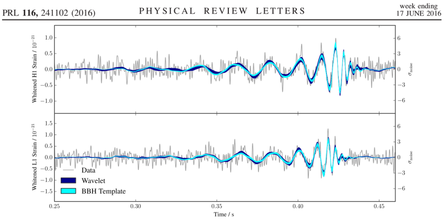


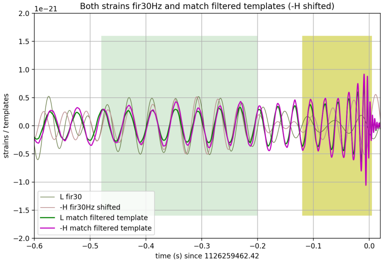




Amplitude spectral density of the strains after bandpass and stopband FIR filters; Hanford on the left and Livingston on the right. We use the same axis limits as in previous graphs in order to facilitate the comparison.

# New pre-processing filtering techniques for GW signals. IV

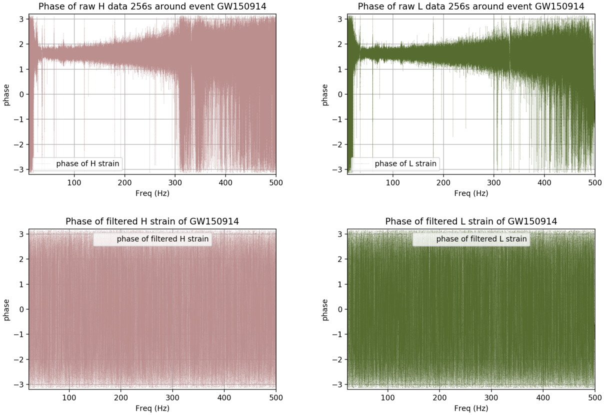
### Strains in the time domain with LIGO filters and with our filtering




On the left, it is shown how the observed data looks like after LIGO whitening filters are applied[Abbott et al.(2016)]; using data sampled at 2048Hz. Notice how the signal is attenuated before 0.1s of the event time. On the right, the strains and the matched templates after applying our filtering; and an extra lowpass 30Hz filter, where one can see that there seems to be astrophysical signal in the lapse from about -0.5s to -0.2s.

**The phase behavior of the strains**

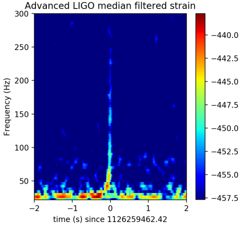



At the top, phase diagrams as a function of frequency for the raw data of 256s length around the time of the event GW150914, showing Hanford on the left and Livingston on the right, and at the bottom, after applying our filtering.

# New pre-processing filtering techniques for GW signals. VI

- It can be seen that phases are evenly distributed in the frequency range of interest.
- This is a strong indication that we were able to suppress the initial phase correlation in the raw data; and also that this correlation was due to the intrinsic excitations of the detectors.
- Of course an evenly distribution of phases is a good sign, since indicates an almost Gaussian noise behavior.

**Spectrogram of the filtered signals**

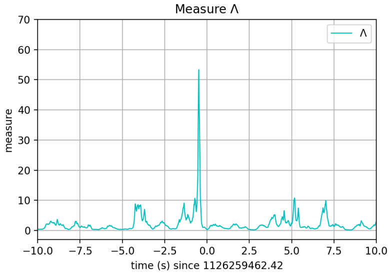


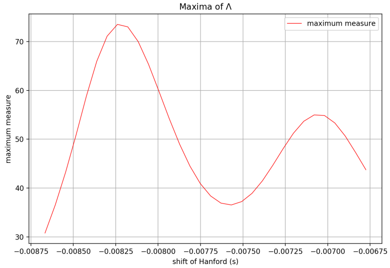

Spectrograms for the median; where the H strain has been inverted and shifted.

# A new measure for the search of similar signals in two detectors. I

**Are there other indications for the existence of more physically interesting signals at earlier times?**

Let $\mathbf{v}_{(1)}(\tau)$ represents the strain at one detector with respect to its proper time, and $\mathbf{v}_{(2)}(\tau - \delta)$ represents the strain at the other detector, with time shift $\delta$. Let $w(t - \tau)$ be an appropriate window, to be used in the calculation of the measure $\Lambda(\mathbf{v}_{(1)}, \mathbf{v}_{(2)}, \delta, t)$. (We can not give the details of the definition in this occasion.)




On the left, measure $\Lambda(t)$ for the shift $\delta = -0.007$s for the Hanford strain. On the right, maxima of the measure as a function of the shift $\delta$ for the (-)H strain, in sample steps, for a window of 0.5s width.

How can the previous graphs be understood?
The noise-free response $R(t)$ of one detector is given by

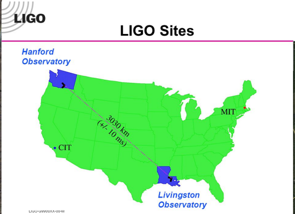
$$R(t) = F_{+}\, h_{+}(t) + F_{\times}\, h_{\times}(t), \tag{1}$$

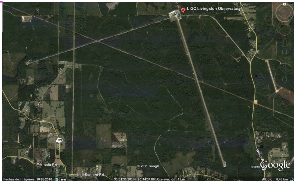
where $F_{+}$ and $F_{\times}$ are functions of the angles describing the orientation of the detector and the position of the source.
The matched templates for each detector, that we could call $h_L(t)$ for Livingston matched template and $h_H(t)$ for Hanford matched template, are the best estimates one has from LIGO to represent the gravitational wave signal contained in the strains.
The qualitative behavior of the expected signal can be modeled[Sathyaprakash and Dhurandhar(1991), Cutler and Flanagan(1994)] by:

$$h(t) = \frac{Q(\text{angles})}{(t_f - t)^{1/4}} \cos\left(\phi_f(\text{angles}) - 2\left[\frac{t_f - t}{5 t_c}\right]^{5/8}\right). \tag{2}$$

It can be seen that amplitude and frequencies are function of $(t_f - t)$, and that the angular dependence will show as a change of phase.

# Detection of the tensor polarization (spin 2) of the GW150914 signal. II



Satellite pictures of both detectors; where one can see a slight different anti orientation with respect to standard angular coordinates. Of course the discrepancy increases when taking into account the curvature of the Earth.

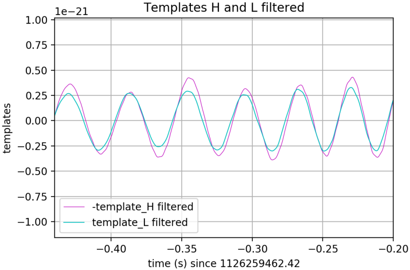
- Different orientations of the detectors with respect to the signal will not change the time position of the highest amplitude, which occurs at the highest frequencies, but will affect with a change of phase the low frequency signals.

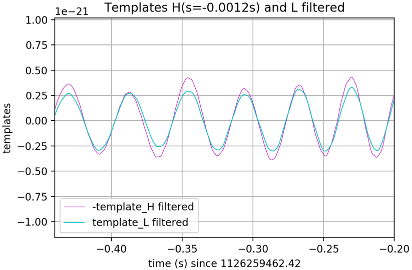
# Detection of the tensor polarization (spin 2) of the GW150914 signal. III

- Therefore, if one is detecting the signal in a rather long interval of time, the maximum of the measure $\Lambda$, as a function of the shift $\delta$, will not coincide with the value $\delta_e$ that marks the time shift between the two detector times at the maximum of the signal, i.e. the time of coalescence, but it will be located at the $\delta$ needed to make the coincidence of phases at lower frequencies, where several cycles contribute to the measure.
- This is an effect that it has not been reported previously and is a clear indication of the nature of the spin weight 2 character (tensor polarization) of the gravitational wave signal.
- The fact that two peaks appear is accentuated by the lack of detection from the Livingston site, in the small lapse of time that goes from about -0.2s to -0.12s[Moreschi(2019)].

# Detection of the tensor polarization (spin 2) of the GW150914 signal. IV

This effect can be observed directly in the matched templates for each detector.




On the left, the matched templates in the range -0.44 to -0.2s, where the (-)H template has been shifted to achieve the coincidence of the maximum with the corresponding L template maximum, and where one can notice a slight phase misalignment, since the maxima of the *H* template are to the right with respect to those of the *L* template, in this range. On the right we show again the matched templates but where the Hanford one has been shifted an extra -0.0012s; noticing the phase agreement afterwards.

- It can be seen that an extra shift of -0.0012s in the H strain, attains an agreement (within the resolution of the graph) of phases at earlier times in the templates.
- We conclude that the peak at about -0.00705s shift, in the right graph of maxima of $\Lambda$, is due to the concordance of both detected signals of only the first 0.1s before the time of the event. And that the second peak, at about -0.00824s, is due to the extra shift needed in order to provide agreement of phases of both signals at lower frequencies at earlier times. Since, the time shift between the two local maxima of the observed data coincides with the phase shift needed to make the two matched theoretical templates to coincide in phase at low frequencies.

All this indicates that the two LIGO strains for the GW150914 event, contain the signal of two polarization components of a spin weight 2 gravitational wave; precluding any spin weight 1 or spin weight 0 interpretation for these signals.

# Final comments I

We have presented a new pre-processing filtering technique for GW150914:

- Our filtering avoids the severe deformation that produces the commonly use whitening techniques.
- Our methods provides strains that have reasonable phase behavior; solving some issues that have been noticed in the literature.
- We have shown that there seems to be an astrophysical signal that extends to about 0.5s previous to the time of the GW150914 event. This is much more than the 0.1s and 0.2s reported in LIGO articles.

◎ The proposed physical signal is very closed to the time of the event.

◎ The proposed physical signal matched perfectly in phase with the theoretical calculation proposed by LIGO.

◎ The proposed physical signal matched approximately in amplitude with the theoretical calculation proposed by LIGO.

◎ The proposed physical signal matched perfectly in frequency for about six cycles with the theoretical calculation proposed by LIGO.

# Final comments II

We have also presented a new measure to look for similar signals in two detectors:

- Our measure allows to infer the spin 2 nature (tensor polarization) of the gravitational waves detected in the LIGO GW150914 event, with just two detectors.
- The signal of this event, then precludes scalar (spin 0) and vector modes (spin 1) in favor of the spin 2 description.
- The appearance of the two local maximums will provide extra information for the localization of the source for the GW150914 event.
- We expect that our measure will become useful in checking possible gravitational lensed black hole mergers.

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# Final comments III

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Did we really find gravitational waves?

Yes! we did!

I am grateful to the LIGO/Virgo Collaboration for making available the observed data and the python scripts on data analysis.

Many thanks to the organizers and Thank You all!

- **LIGO Scientific, Virgo** Collaboration, B. P. Abbott *et al.*, "Properties of the Binary Black Hole Merger GW150914", *Phys. Rev. Lett.* **116** (2016), no. 24, 241102, `arXiv:1602.03840`.
- B. S. Sathyaprakash and S. V. Dhurandhar, "Choice of filters for the detection of gravitational waves from coalescing binaries", *Phys. Rev.* **D44** (1991) 3819–3834.
- C. Cutler and E. E. Flanagan, "Gravitational waves from merging compact binaries: How accurately can one extract the binary's parameters from the inspiral wave form?", *Phys. Rev.* **D49** (1994) 2658–2697, `arXiv:gr-qc/9402014`.
- O. M. Moreschi, "Convenient filtering techniques for LIGO strain of the GW150914 event", *JCAP* **1904** (2019) 032, `arXiv:1903.00546`.