Talk Astro #4

Christopher Alléné
JRJC 2022

Study of the localization of sources identified by the MBTA pipeline for low latency CBC search and Early Warnings

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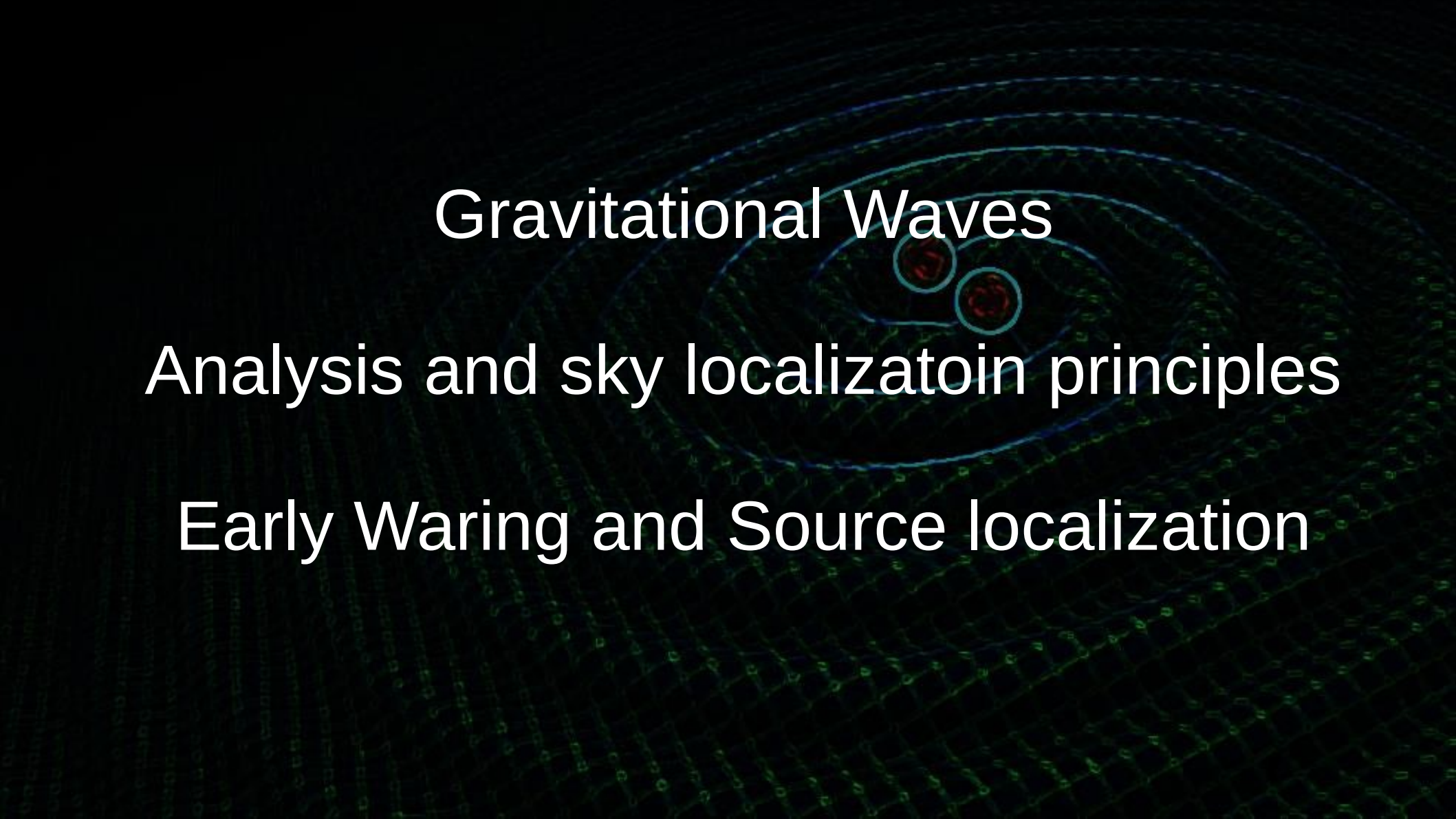
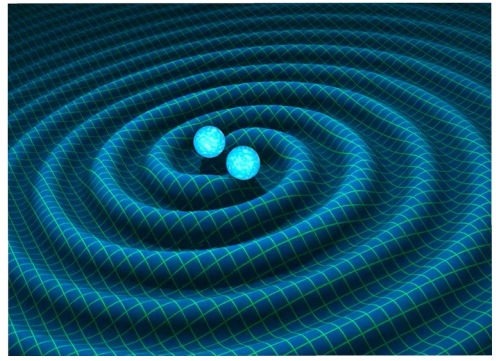

Gravitational Waves
Analysis and sky localizatoin principles
Early Waring and Source localization


Gravitational Waves

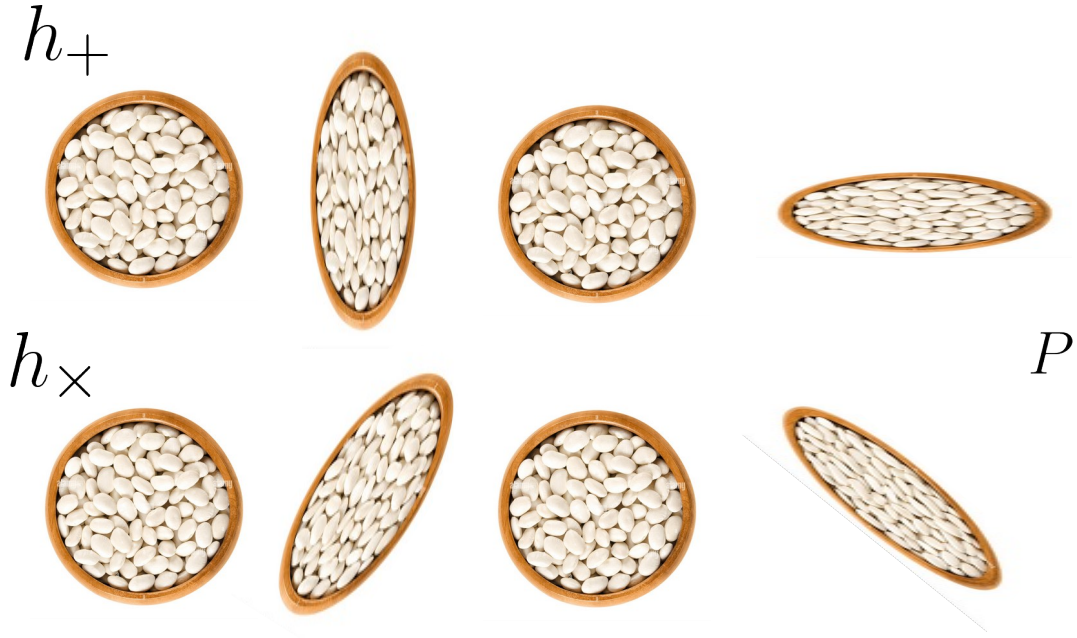
Gravitational Waves (GW)

Space-time Metric perturbation :

- General Relativity (1916) ;
- Gravity speed : c
- Two polarisations h_+ et $h_\times$



Emission if rotation around an axis which is not of symmetry.

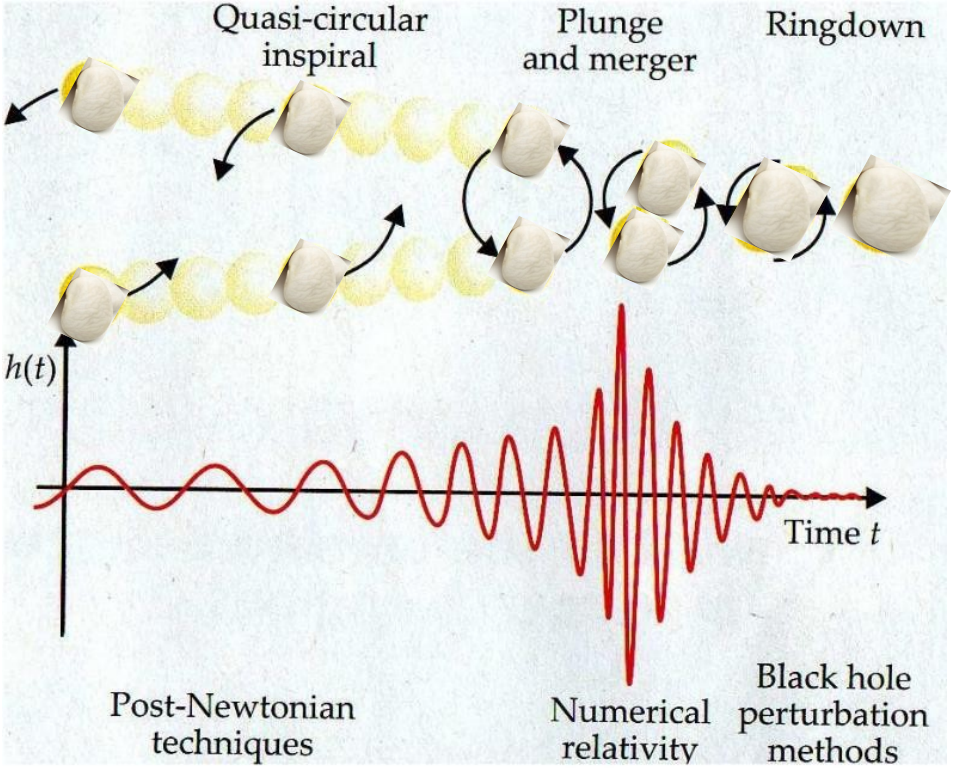


Puissance émise par une source :

$$P \simeq \frac{c^5}{G}\epsilon^2 \left(\frac{R_S}{\Delta}\right)^2 \left(\frac{v}{c}\right)^6 \propto \frac{G}{c^5} \sim 10^{-53} SI$$

Binary Neutron Stars (BNS), Binary Black Holes (BBH) and Neutron Star-Black Hole (NSBH) systems

Compact Binary Coalescence



- Depends only on the chirp mass at newtonian order :

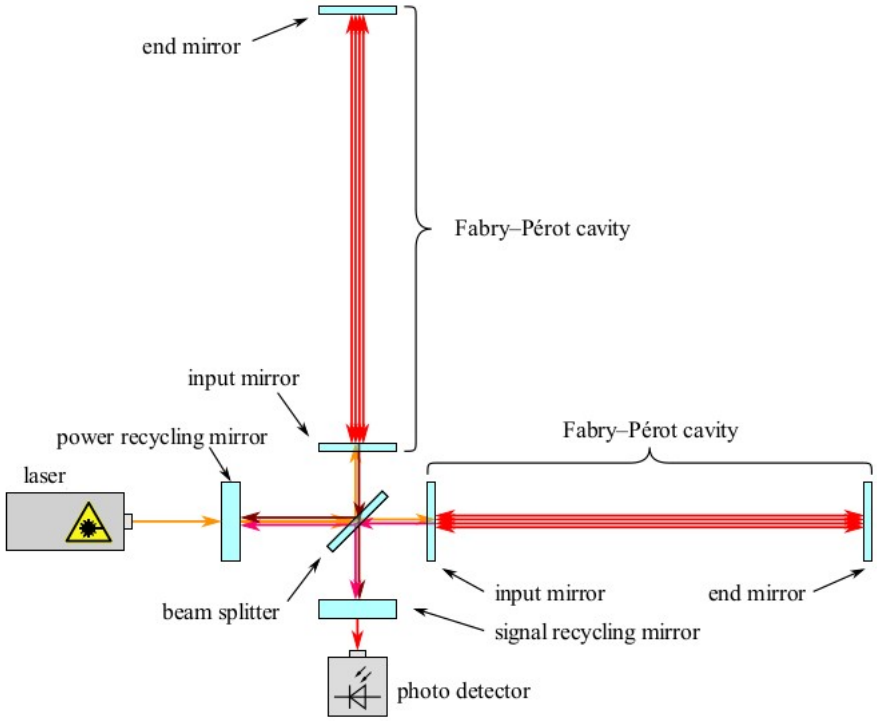
$$\mathcal{M} = \frac{(m_1 m_2)^{\frac{3}{5}}}{(m_1 + m_2)^{\frac{1}{5}}}$$

- Inspiral phase stops at the innermost stable circular orbit (ISCO).

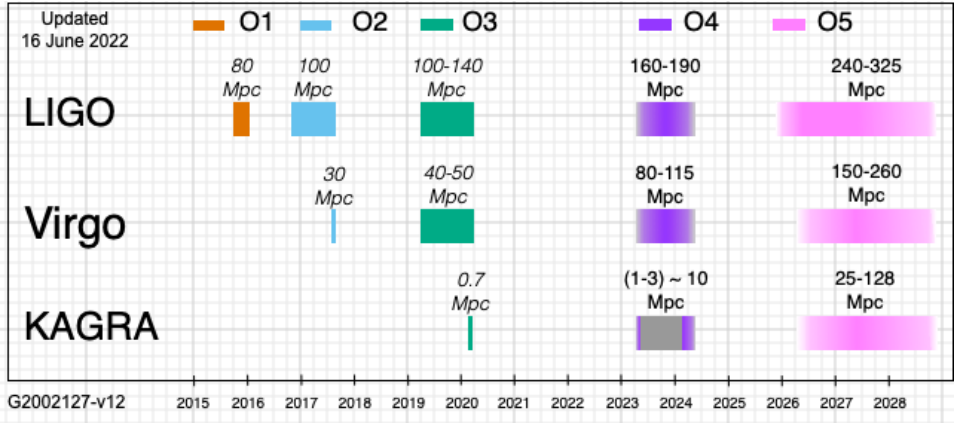
GW detectors

How to detect deformation of 10^{-21} ~(size of a mogette / size of a small galaxy) ?

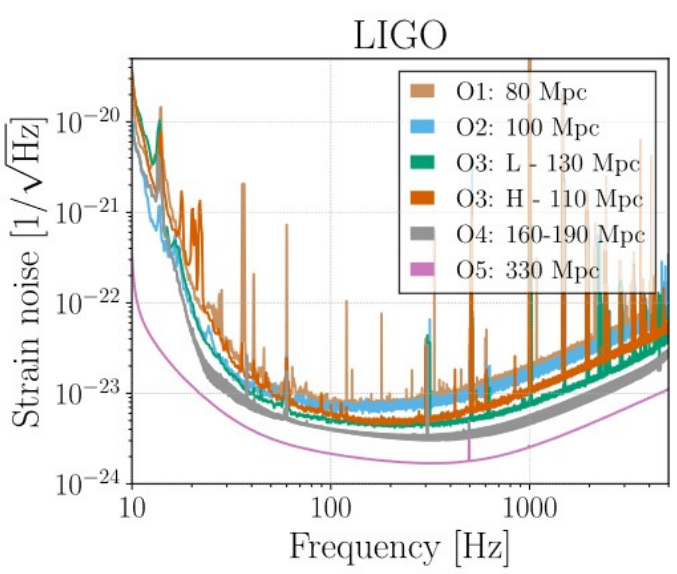
Interferometer outline

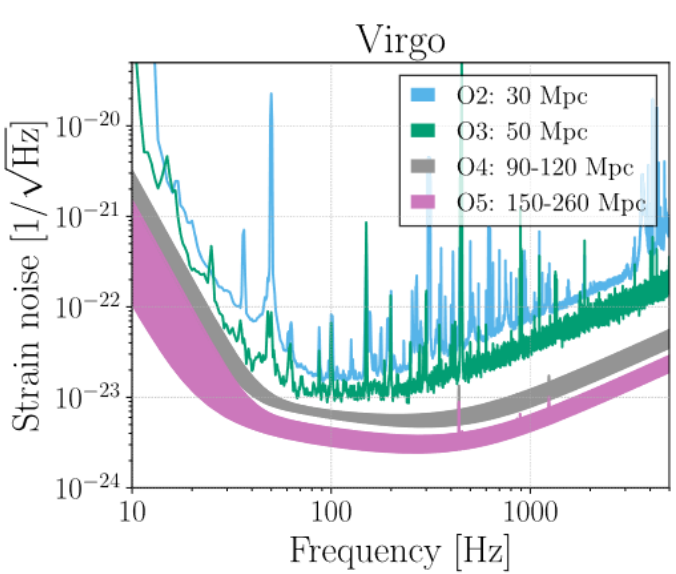


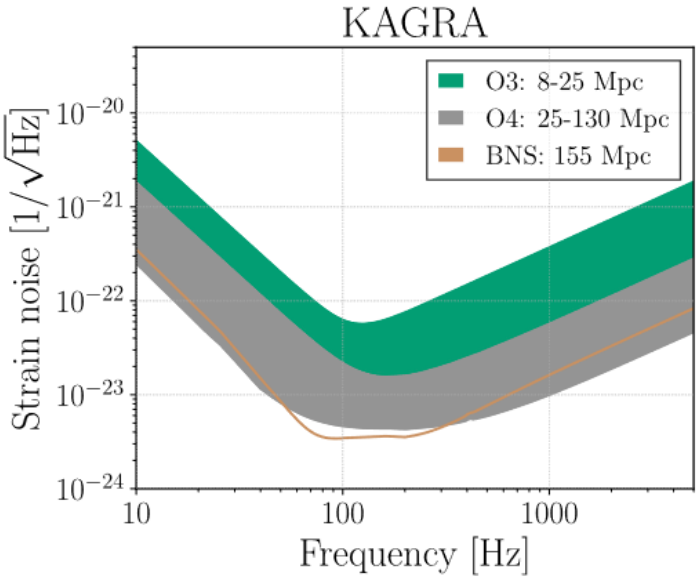
Interferometer network



GW detectors



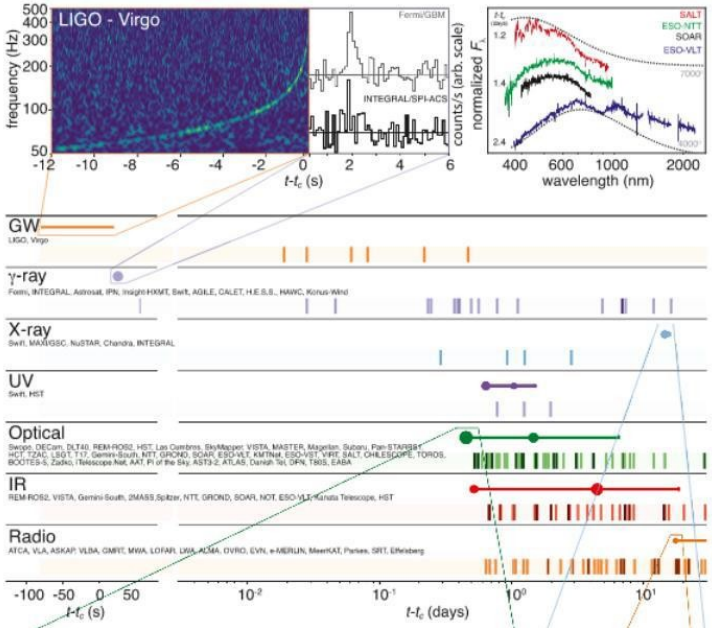


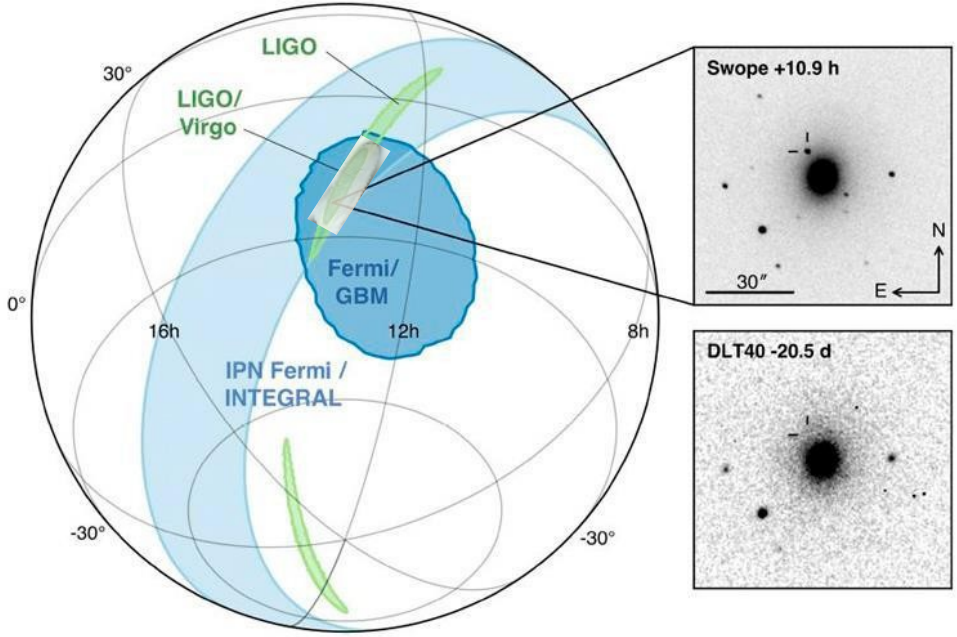


Detectors sensitivity : The sensitivities and ranges for O4 and O5 are prospects

Multi-messenger detections : GW170817

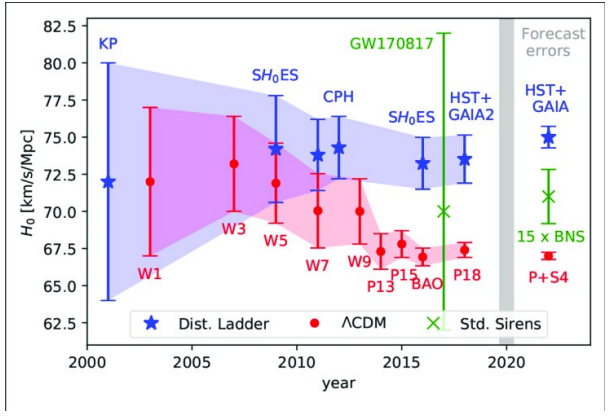
- First and only multi-messenger detection ;
- Observed the 17th of august 2017 ;
- Binary Neutron star coalescence ;
- Identified as a kilonovae ;
- Localized in NGC4993 ;





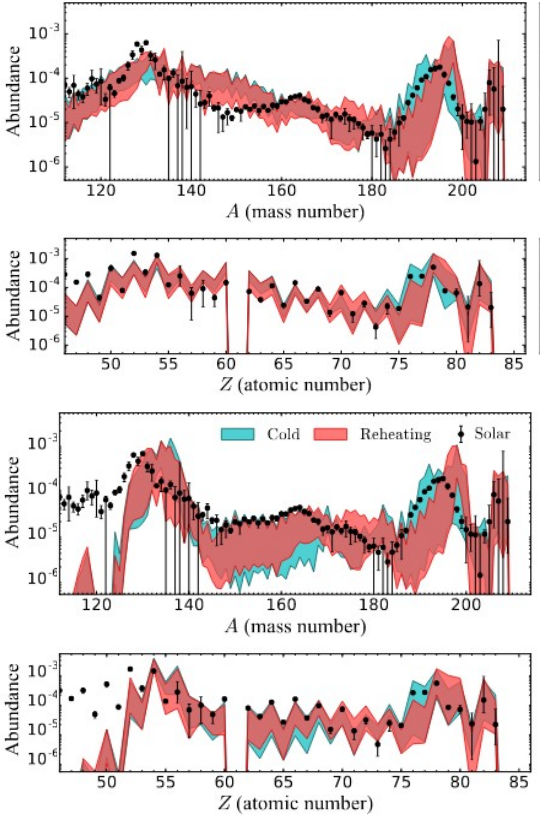
Multi-messenger detections : GW170817

Hubble Constant H_0 measurment (needs more events to have a better precision)

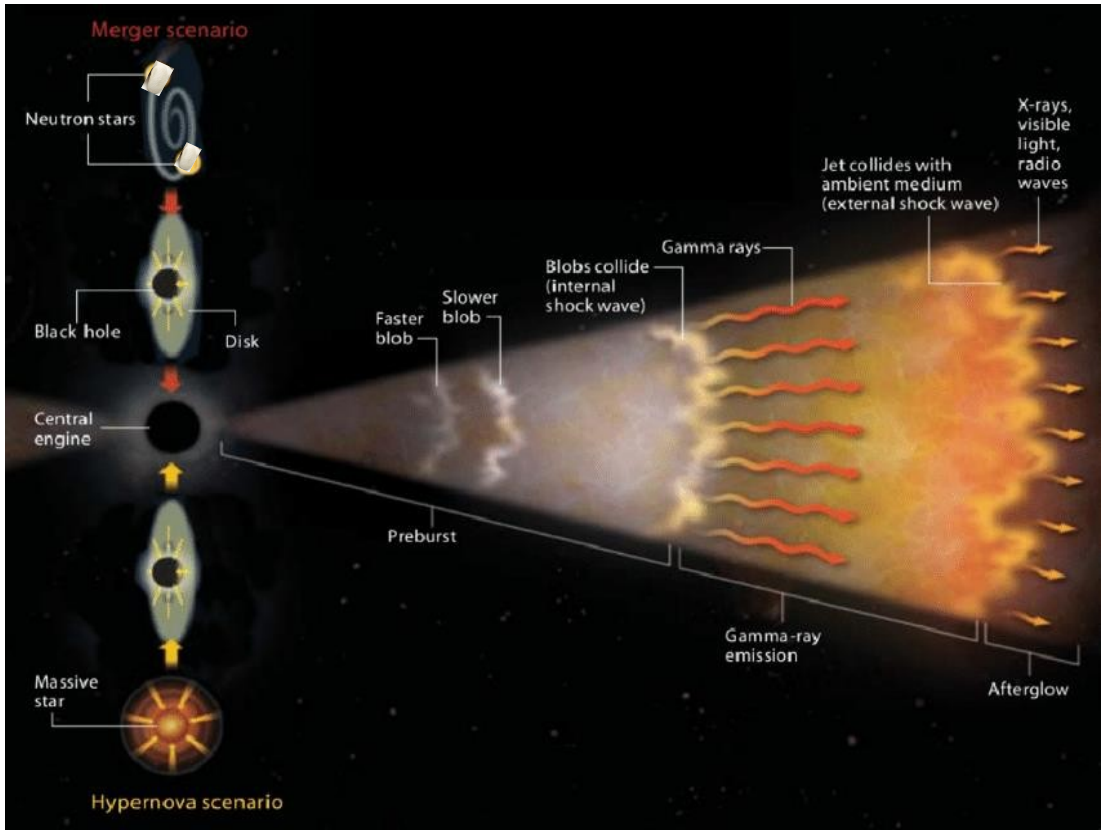


Neutron star EoS and core composition :
- Neutrons ?
- Mogettes ?
- Foutimassons ?
- Something else ?

Heavy elements abundances (mogettes and foutiamssons not included)



Multi-messenger detections : GW170817



Global objectif : Get more multi-messenger detections.

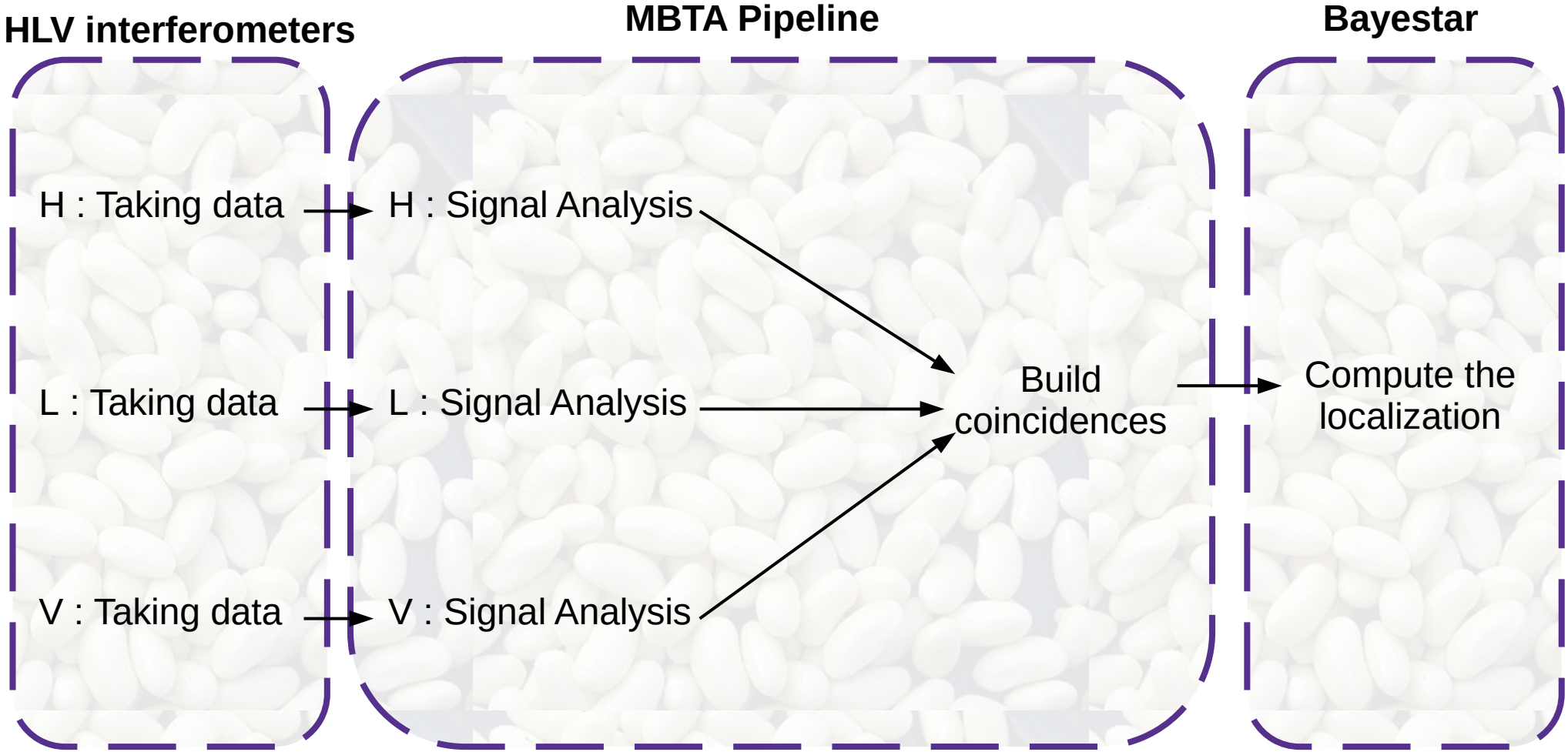
This needs :

- The detectors and their sensitivity improvement ;
- Analysis optimization and quickening;
  - Do Early Warning ;
- Precise source localization ;
  - Lacalization of Early Warning to send Early Alerts ;

⇒ **Instruments orientation to have EM multi-messenger detections**

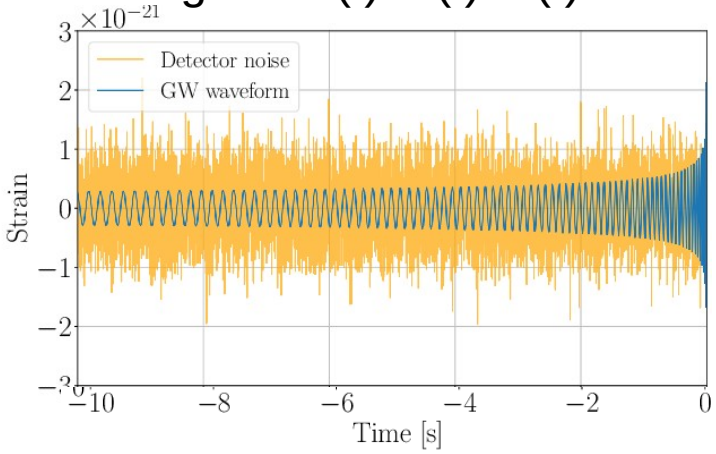
Analysis and sky localizatoin principles

GW detection steps



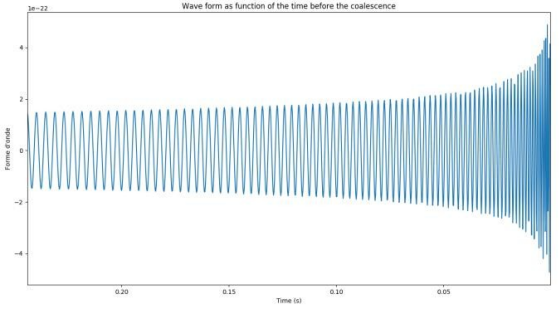
Optimal Filtering : MBTA

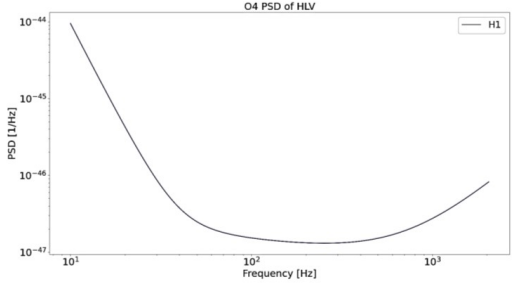
The signal : s(t)=h(t)+n(t)



Frequency domain filter :

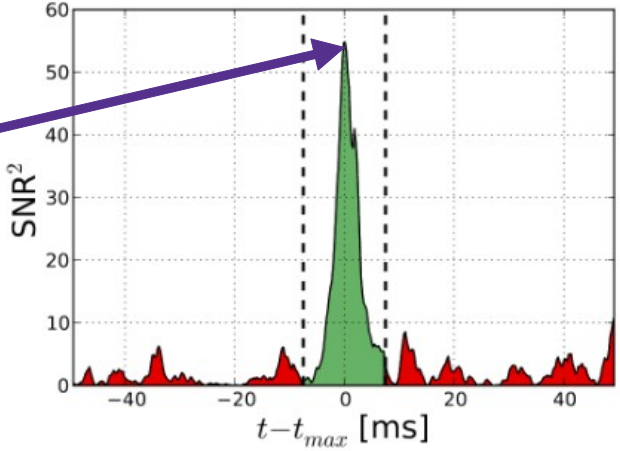
$$\tilde{Q} = 2\frac{\tilde{h}(f)}{S_n(f)} \longrightarrow S = \int_{-\infty}^{+\infty} \tilde{s}(f)\tilde{Q}^*(f)\mathrm{d}f$$





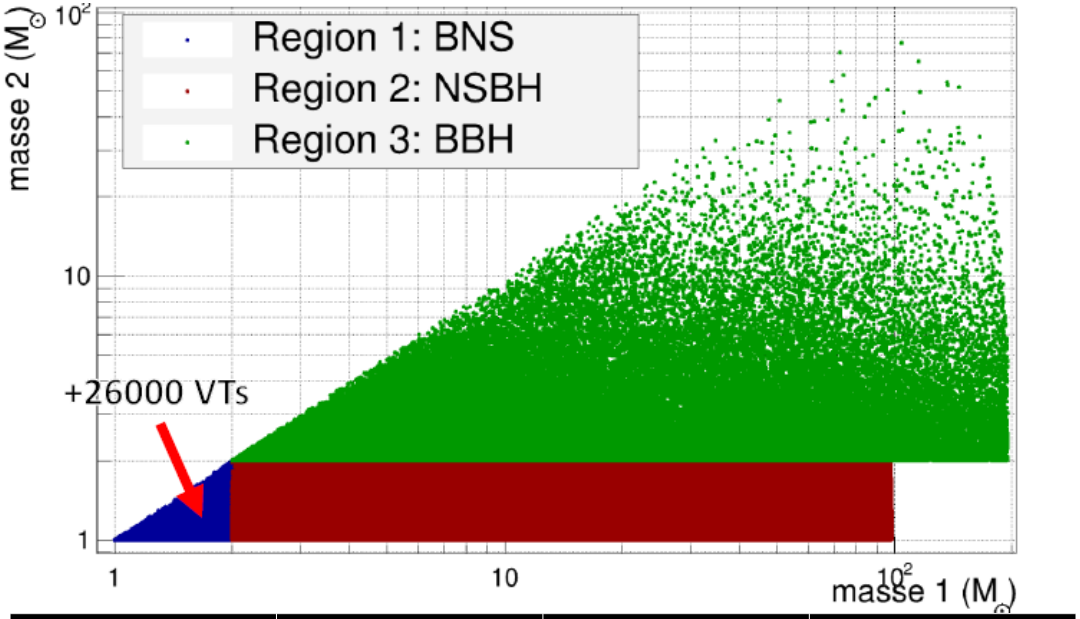
The signal-to-noise ratio (SNR) :

$$SNR = 2\sqrt{\int_0^{+\infty} \frac{|\tilde{h}(f)|^2}{S_n(f)}\mathrm{d}f}$$



Optimal Filtering : MBTA

Template distribution as a function of m_1 and m_2



Region	BNS	NSBH	BBH
$SNR_{threshold}$	4.5	4.8	4.8

The parameter space is such as, any CBC signal has :

$$SNR \geq 97\ \%\ SNR_{opt}$$

Their is an event if :

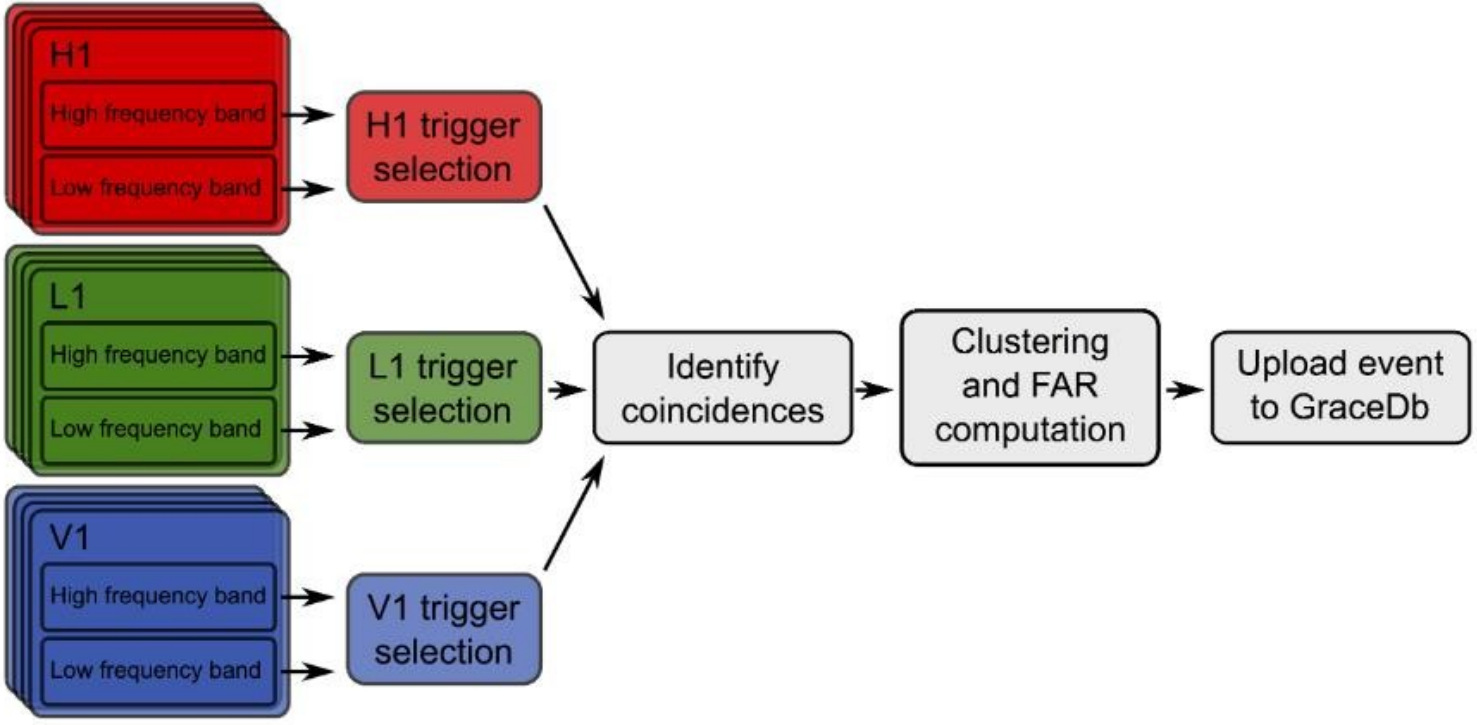
$$SNR \geq SNR_{threshold}$$

With $SNR_{threshold}$ depending on the region.

Optimal Filtering : MBTA

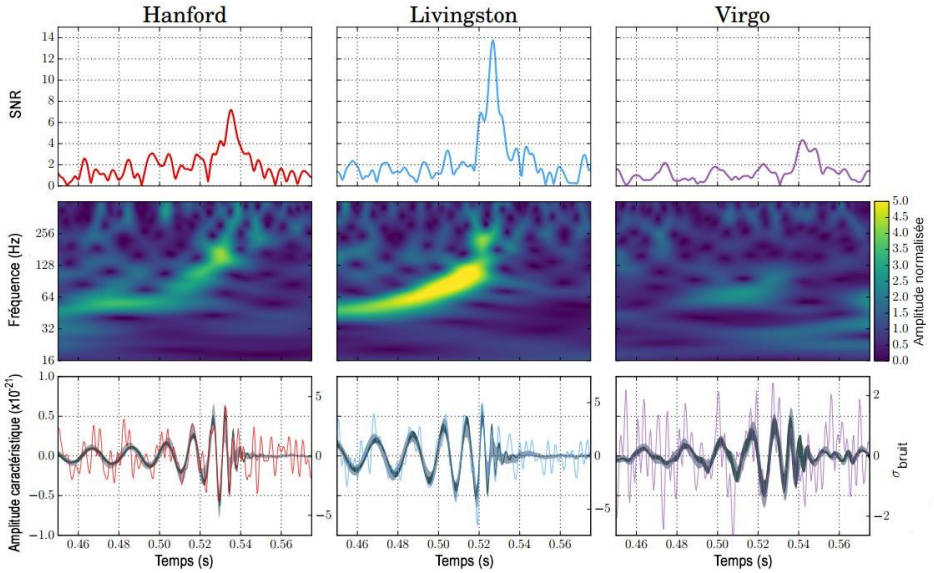
MBTA = Multi-Band Template Analysis

Principle : To cut the frequency band in 2 smaller bands (high/low frequency) to filter then recombine them.



Source localization : Bayestar

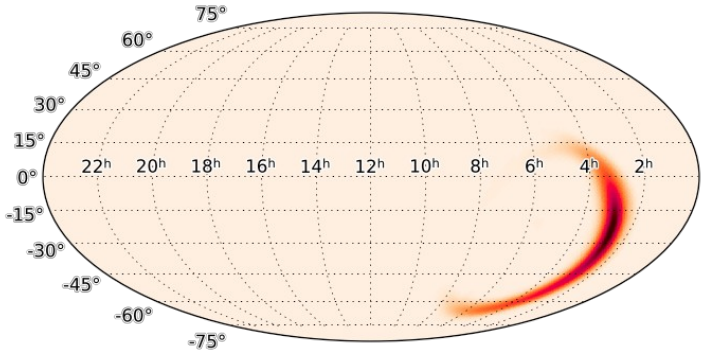
SNR time series :



GW170814

Bayestar

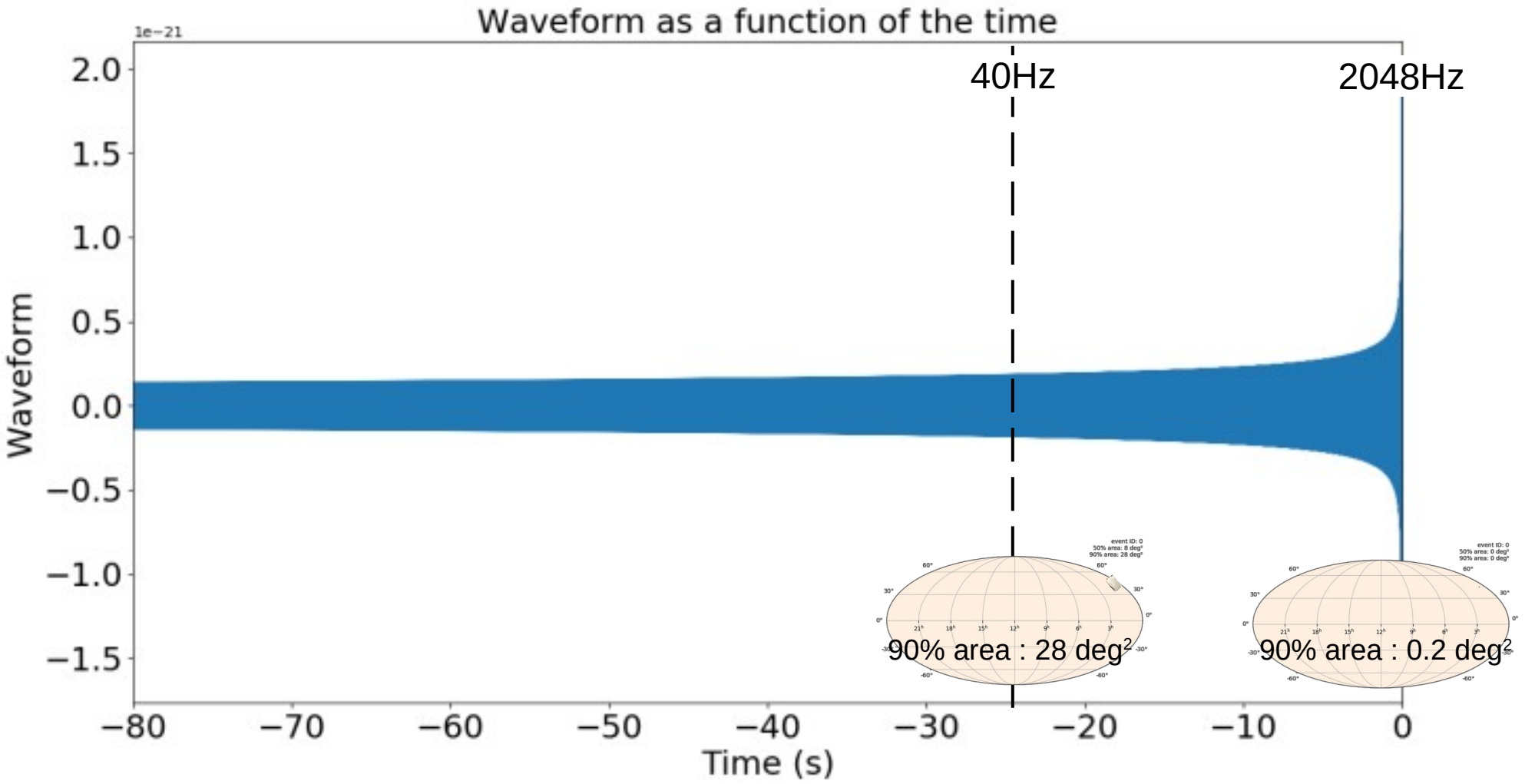
Event localization :



Bayestar : Produces probability of location skymap


Early Waring and Source localization

Early Warning



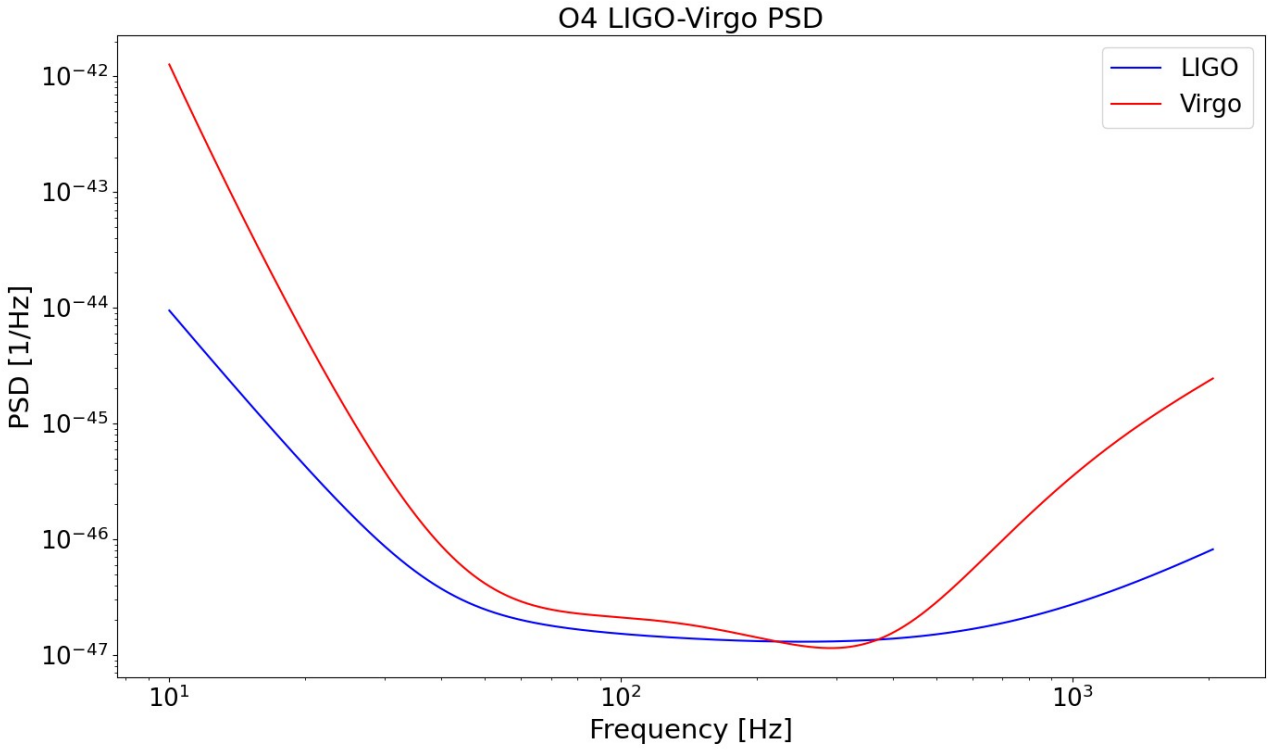
Power Spectral Density (PSD)

Unilateral Density :

$$S_n(f) = \begin{cases} 0, & if \;\; f < 0 \\ |\tilde{n}(-f)|^2 + |\tilde{n}(f)|^2, & if \;\; f \geq 0 \end{cases}$$

About simulations :

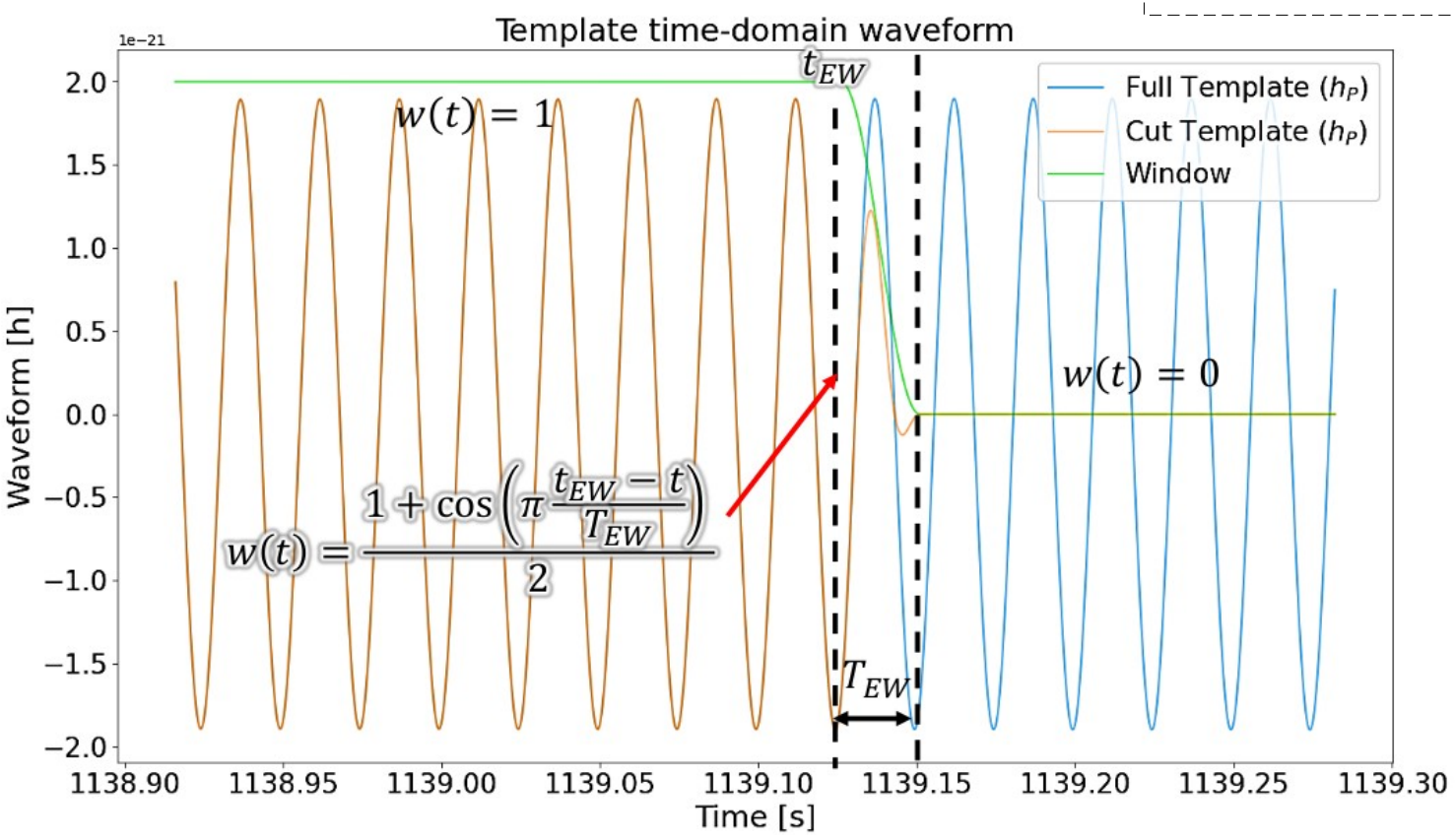
- Theoretical PSD from LALSuite ;
- Of the order of O4 predictions ;
- Same for H and L ;



Template tapering

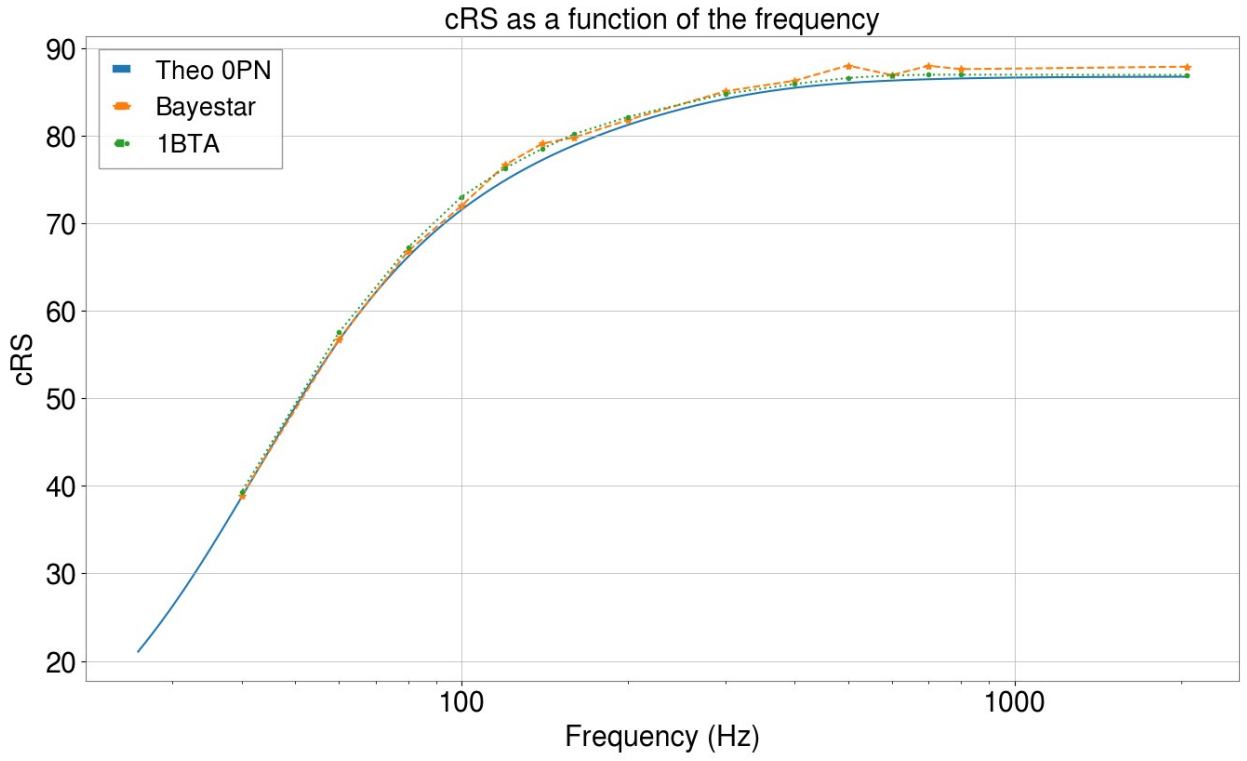
Taper the template at a given frequency with a Tukey window.
At f = 40Hz then t_{EW}= 25s and T_{EW} = 25ms.

t_{EW} : beginning of the tapering
T_{EW} : window duration



SNR Evolution with Early Warning

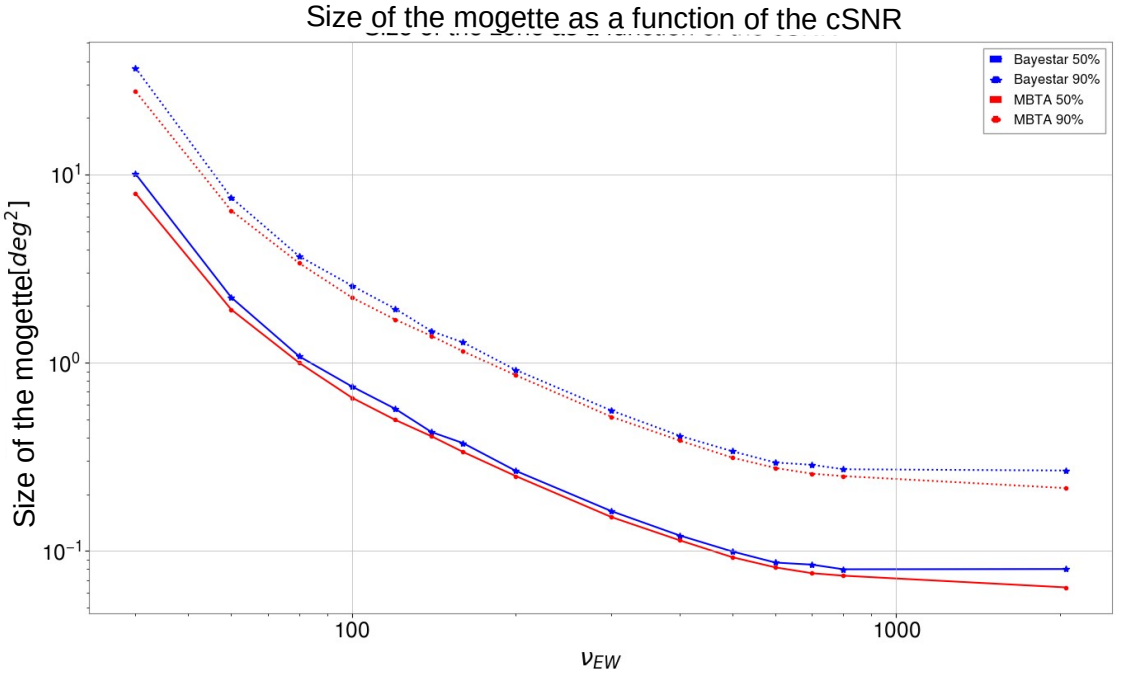
- Test on a 1.4 − 1.4Msol BNS event at 50 Mpc ;
- Lower frequency at 10Hz ;
- Gaussian Noise ;
- One band analysis ;
- Cutoff on the template maximum frequency ;



Mogette Evolution with Early Warning

Bayestar localize the events :

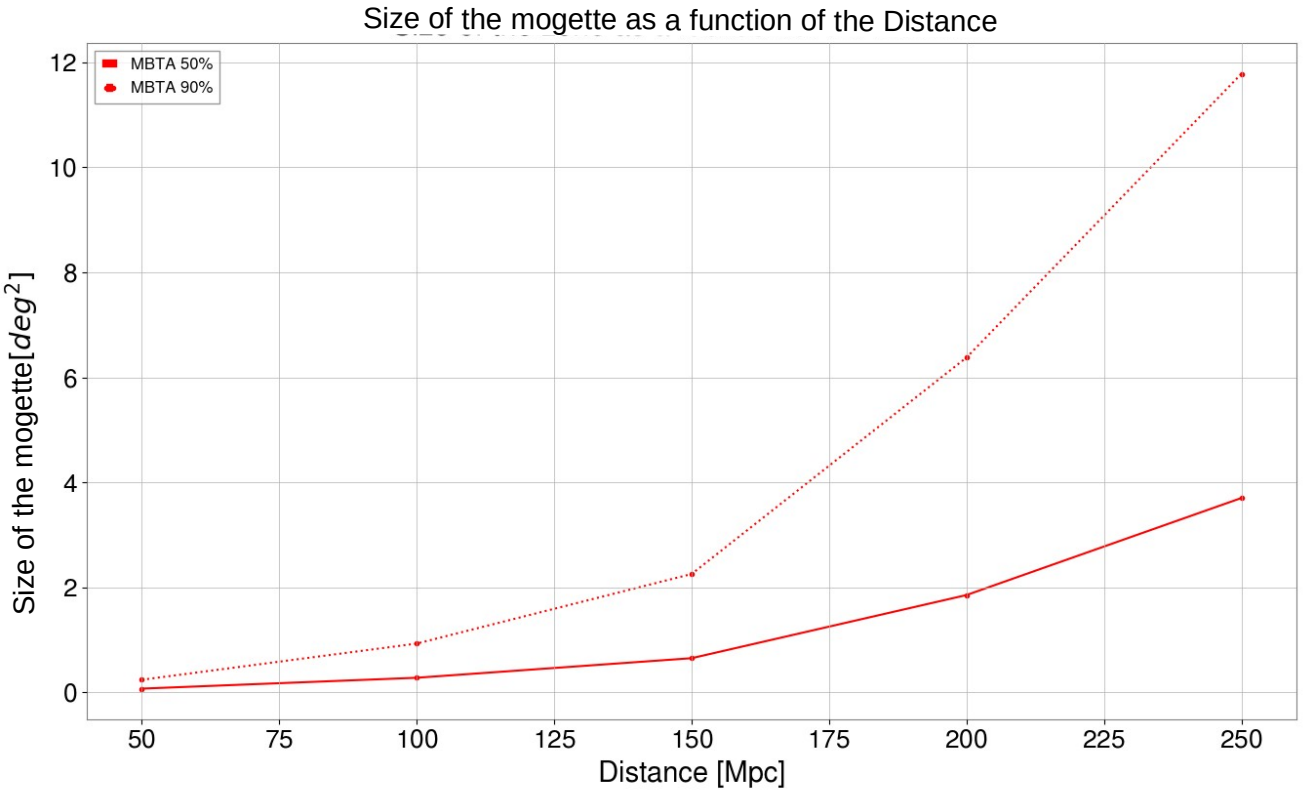
- In blue : Theoretical expectations from Bayestar
- In red : Localization from MBTA events with Bayestar



Mogette Evolution with SNR

Mogette size for the same event at several distances (from 50 to 250 Mpc) ;

And also : $SNR \propto \frac{1}{D}$

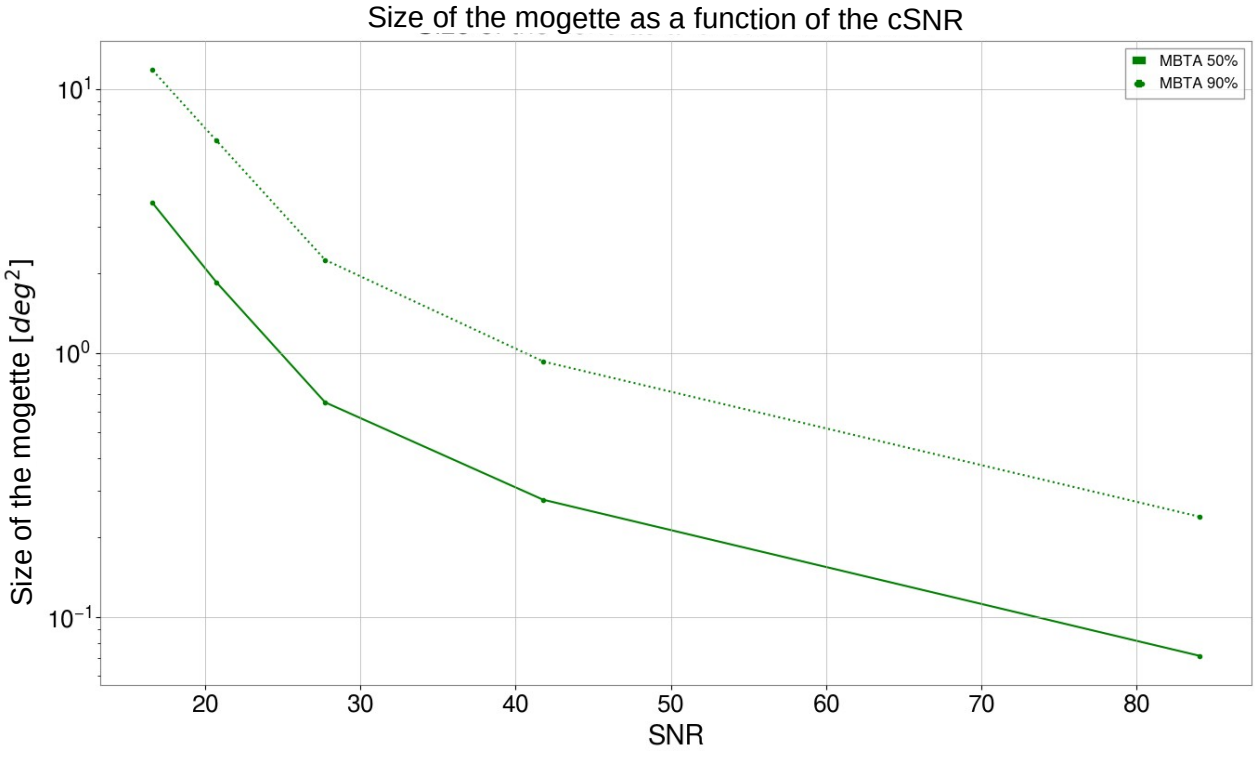


Mogette Evolution with SNR

Mogette size for the same event at several distances (from 50 to 250 Mpc) ;

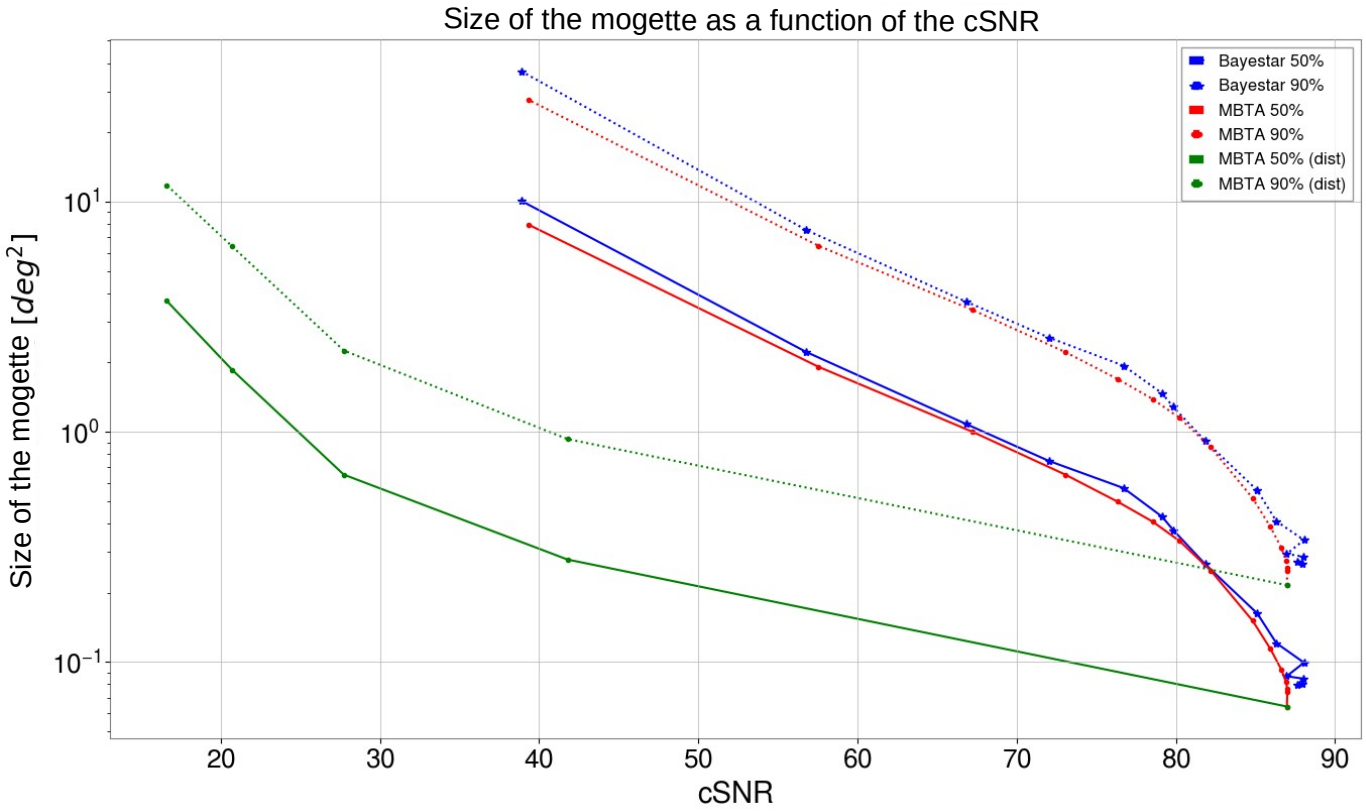
And also : $SNR \propto \frac{1}{D}$

⇒ **Mogette size evolution as a function of the measured SNR.**



Mogette Evolution

The mogette evolution with frequency is compared to the evolution with distance through their SNR.



Continuation

Elaborate the Early Warning strategy for O4 :

- High frequency(ies) cutoff ? ;
- Rejection (χ^2 cutoff, FAR…);
- Parallel analyses;
- …

Next Steps :

- Try on MDC data (O3 recolored to O4) ;
- Study the chirp mass dependency ;
- Eat my new mogettes ;

Summary

- MBTA follows the theoretical expectations for the early detections ;
- It thus follows them for the localization ;
- The mogette size isn’t only SNR dependent ;


Thanks

Foutimasson recipe

Ingredients :

- 1 kg of flour ;
- 200g of butter ;
- 250g of sugar ;
- 6 eggs ;
- 10 cl of milk ;
- 20g of salt ;
- Rhum ;
- 40g of yeast ;
- Frying oil ;
- Icing sugar ;

Recipe :

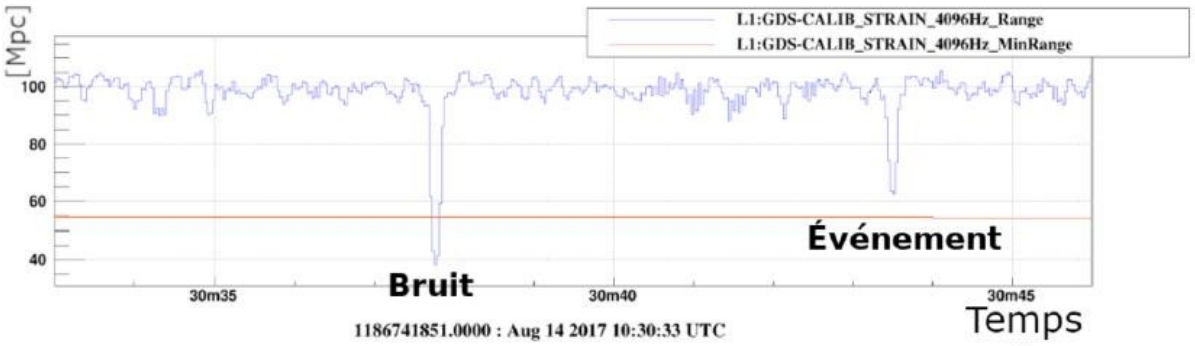
- Creat a little well with the flour ;
- Break the eggs in the center of the well then add the sugar, the salt, the milk, the yeast and the melted butter ;
- Knead until you have a soft dough ;
- Let the dough raise for 1 hour ;
- Lower the dough with a rolling pin ;
- Cut little diamonds in the dough with a knife ;
- Dive the diamonds in the oil at 180°C ;
- Remove them once they are colored ;
- Remove the remaining fat ;
- Sprinkle with icing sugar ;

Gating

Detector Range :

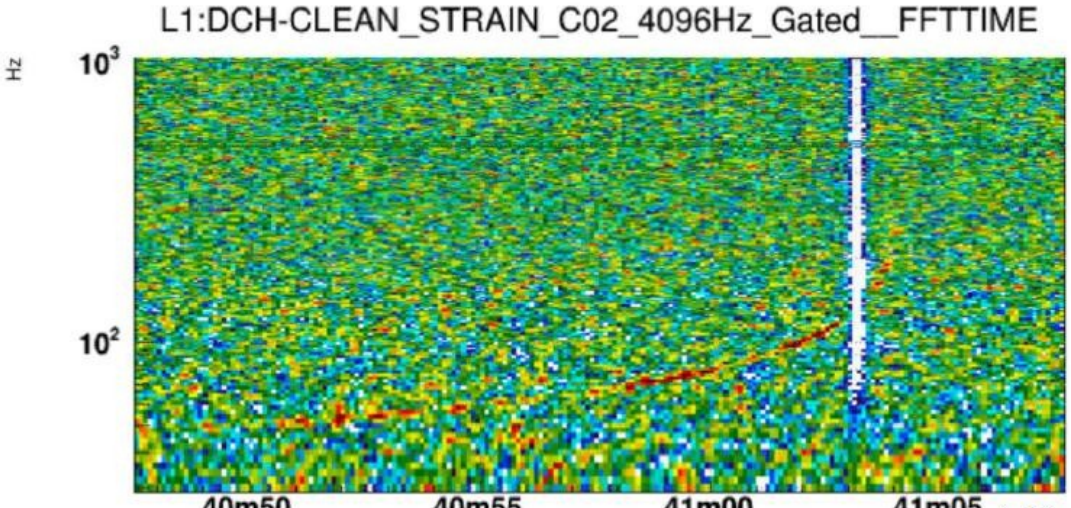
$$R = \frac{1}{2.26\rho}\frac{(\mathcal{G}\mathcal{M})^{5/6}}{\pi^{2/3}c^{3/2}}\sqrt{\frac{5}{6}\int_{f_{min}}^{f_{max}}\frac{f^{7/3}}{S_n(f)}\mathrm{d}f}$$

Distance such as a standard BNS (m_1=1.4M_{sol}, m_2=1.4M_{sol}) has SNR=8.



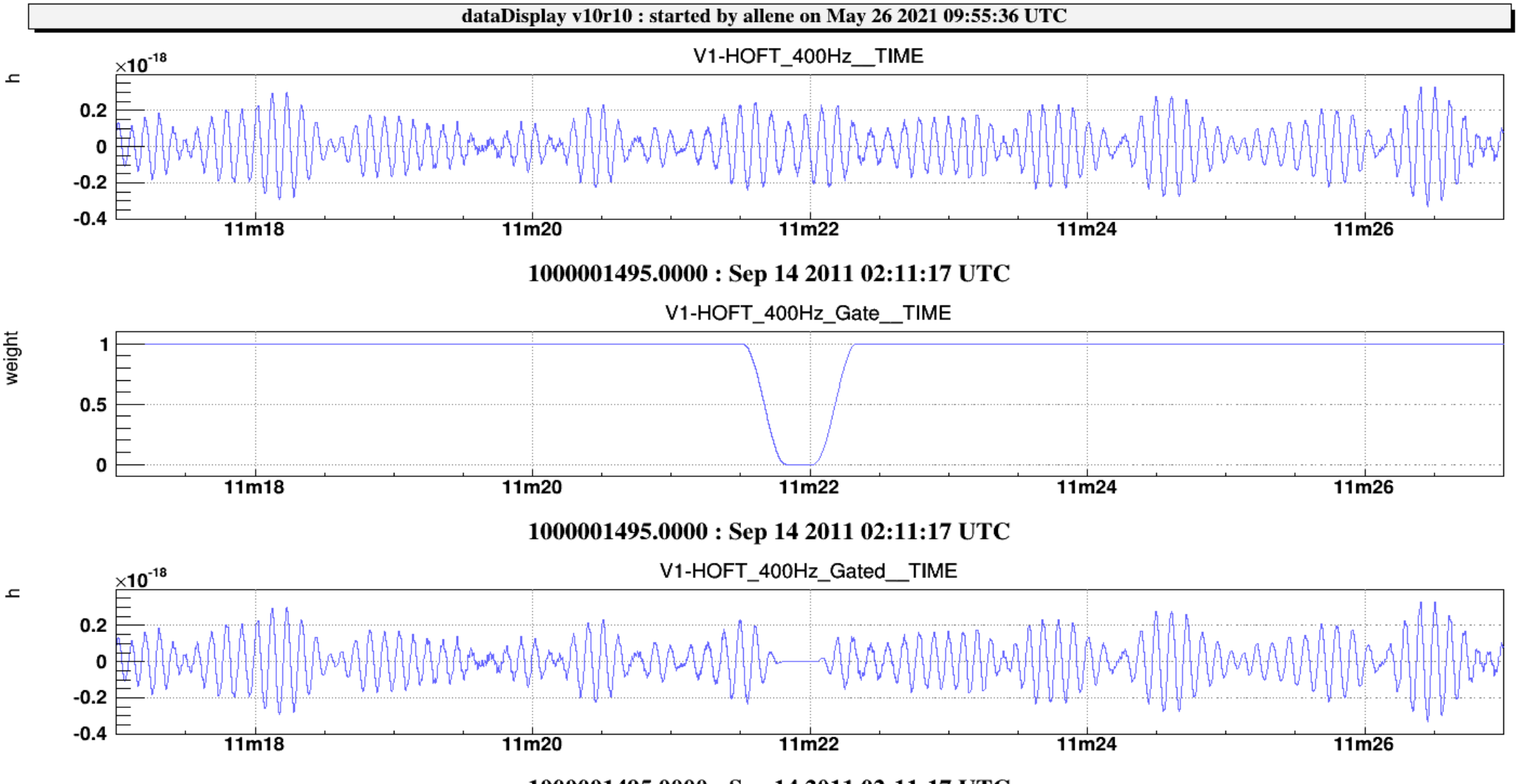
Aubin, 2020

Gating : Tukey window when the noise is too strong ($R<0.6R_{median}$) on a short time.



Aubin, 2020

Gating


dataDisplay v10r10 : started by allene on May 26 2021 09:55:36 UTC
V1-HOFT_400Hz__TIME
h
×10^-18
0.2
0
-0.2
-0.4
11m18
11m20
11m22
11m24
11m26
1000001495.0000 : Sep 14 2011 02:11:17 UTC
V1-HOFT_400Hz_Gate__TIME
weight
1
0.5
0
11m18
11m20
11m22
11m24
11m26
1000001495.0000 : Sep 14 2011 02:11:17 UTC
V1-HOFT_400Hz_Gated__TIME
h
×10^-18
0.2
0
-0.2
-0.4
11m18
11m20
11m22
11m24
11m26