Time-frequency domain coherent search from ground-based detector to LISA

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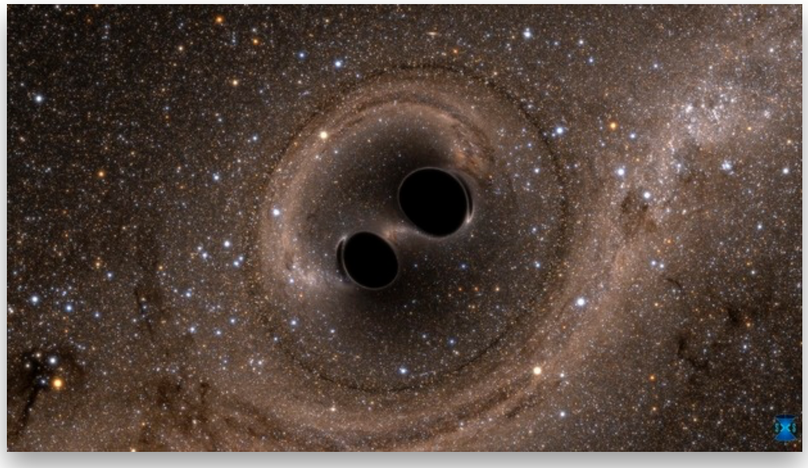
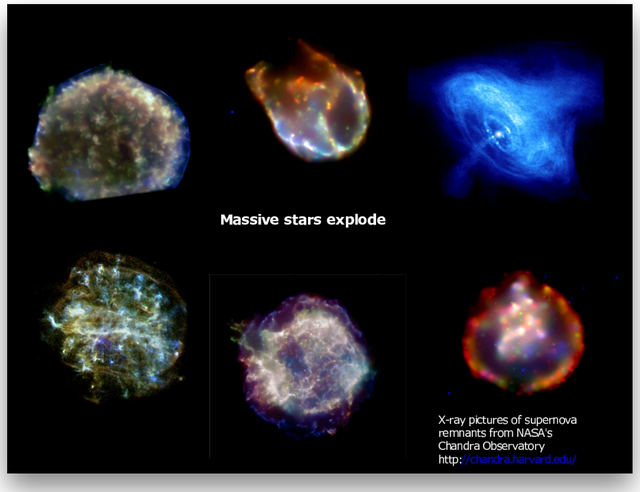
Source of GWs transient signals

For which we have precise models



- Compact binary coalescence
  - Binary Neutron Stars
  - Binary Black Holes
  - Black Hole - Neutron Stars
- Cosmic strings

For which we don't

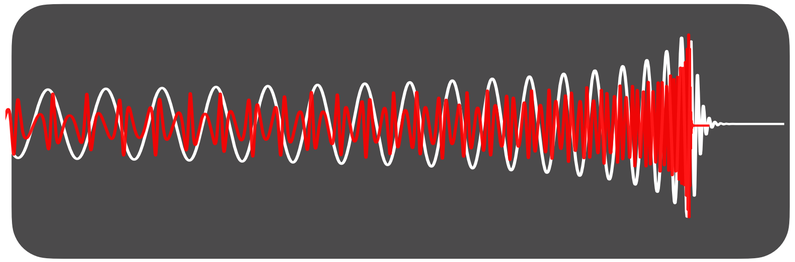


- Supernovae
- Extreme CBC
  - highly eccentric
  - highly precessing, high mass ratio etc
  - exotic companions
- Hyperbolic encounters
- Non-linear memory effect
- Lensing
- …

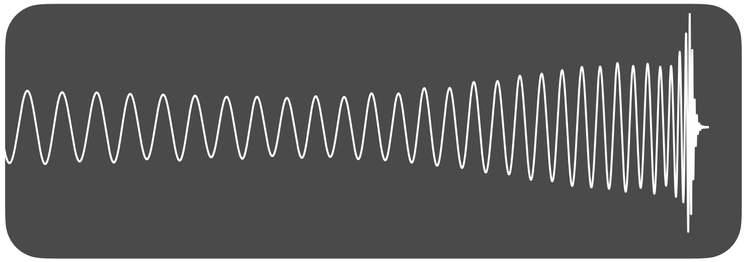
Time domain waveform

Phase and amplitude tells us the information of source

Eccentricity



Precession



Tidal effect

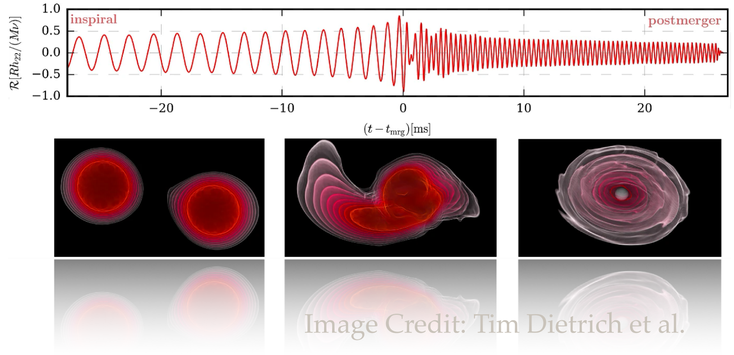
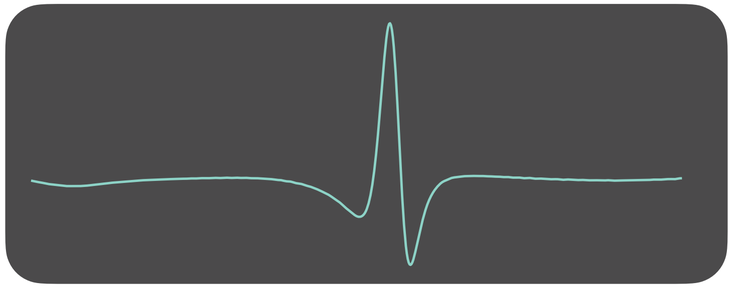
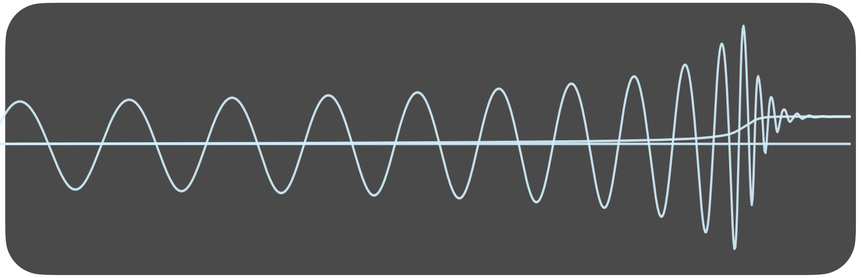


Image Credit: Tim Dietrich et al.

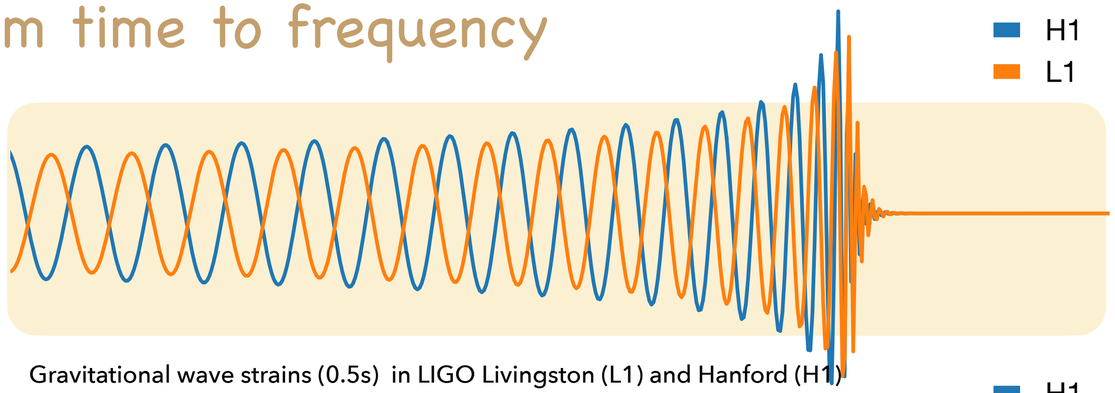
Hyperbolic



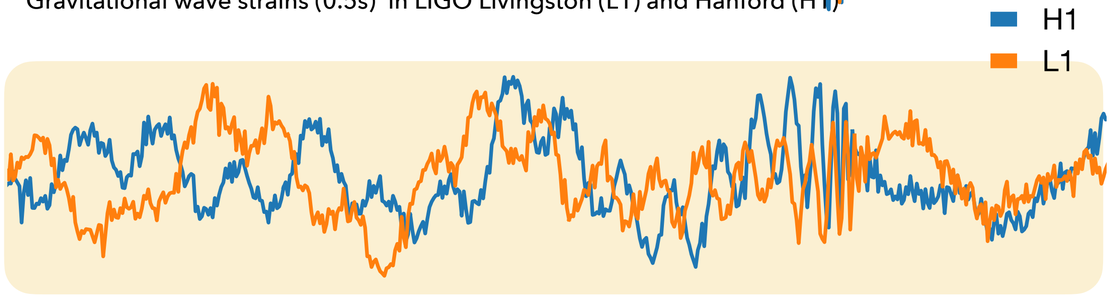
Memory



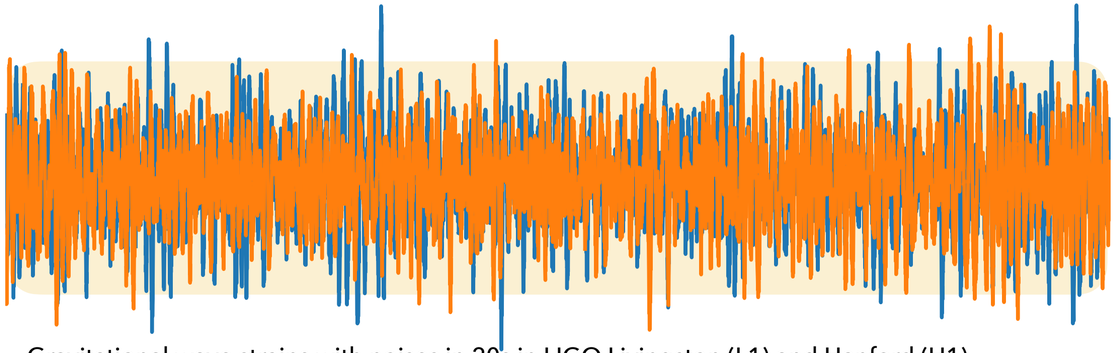
From time to frequency



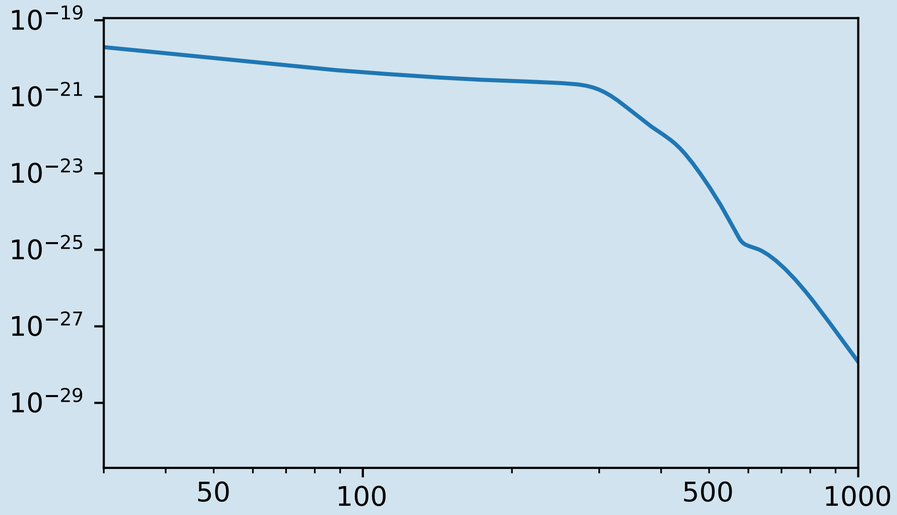
Gravitational wave strains (0.5s) in LIGO Livingston (L1) and Hanford (H1)



Gravitational wave strains with noises (0.5s) in LIGO Livingston (L1) and Hanford (H1)

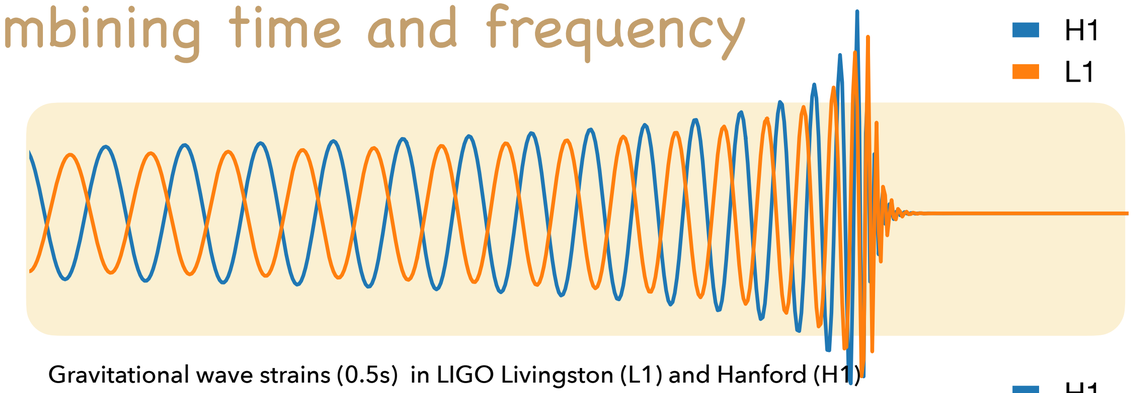


Gravitational wave strains with noises in 20s in LIGO Livingston (L1) and Hanford (H1)

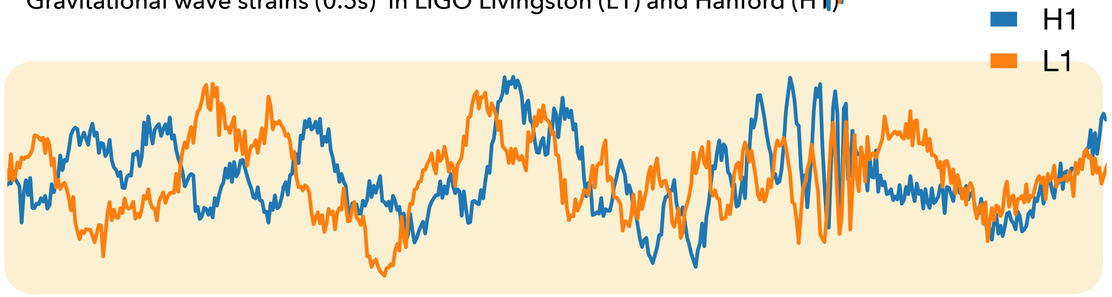


- Can see excess energy in frequencies
- Normally used for match-filtering and parameter estimation
- Loss the information of time-evolution

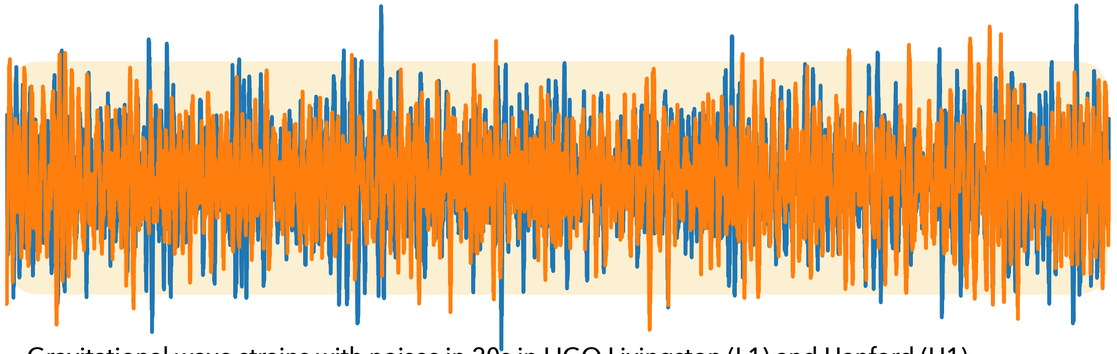
Combining time and frequency



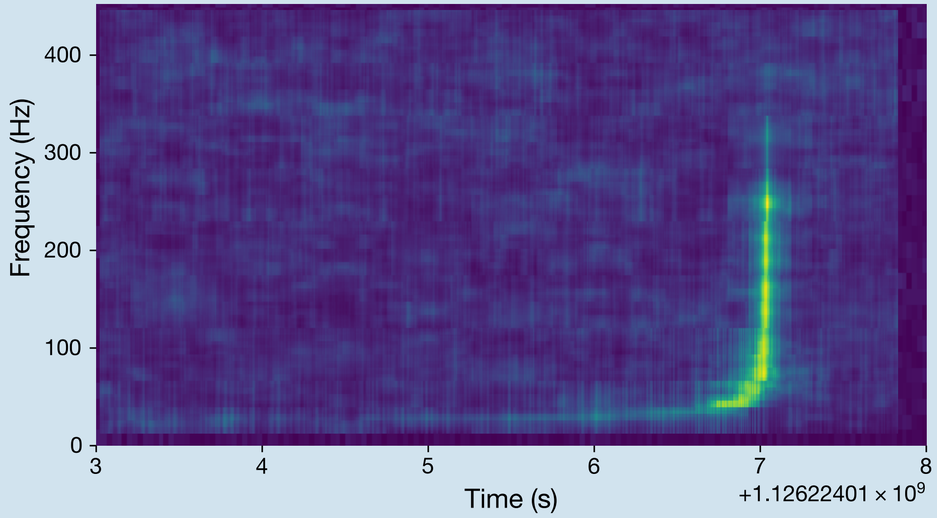
Gravitational wave strains (0.5s) in LIGO Livingston (L1) and Hanford (H1)



Gravitational wave strains with noises (0.5s) in LIGO Livingston (L1) and Hanford (H1)

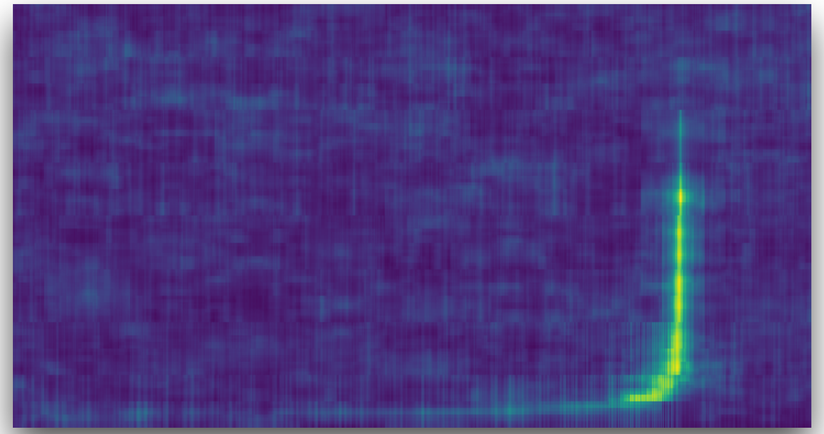


Gravitational wave strains with noises in 20s in LIGO Livingston (L1) and Hanford (H1)

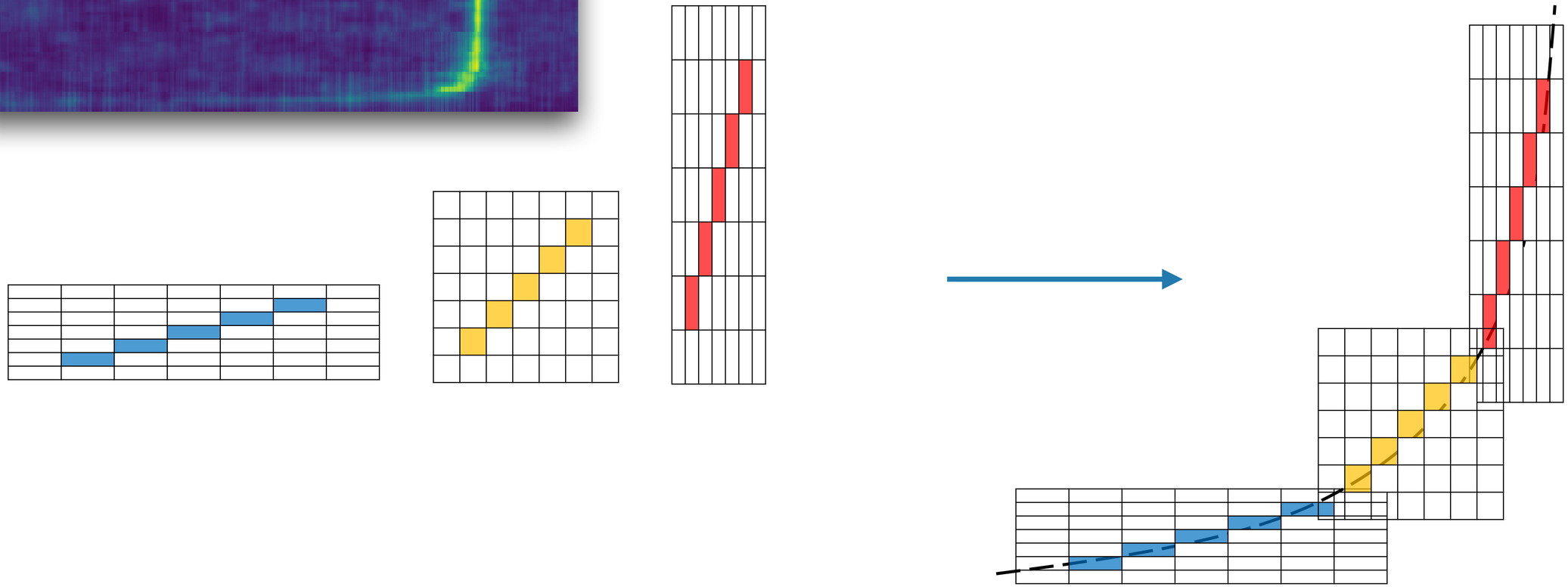


- Show the energy in time frequency pixels
- Visualize the time-frequency evolution
- Trade off in time / frequency uncertainty

Multi-resolution analysis

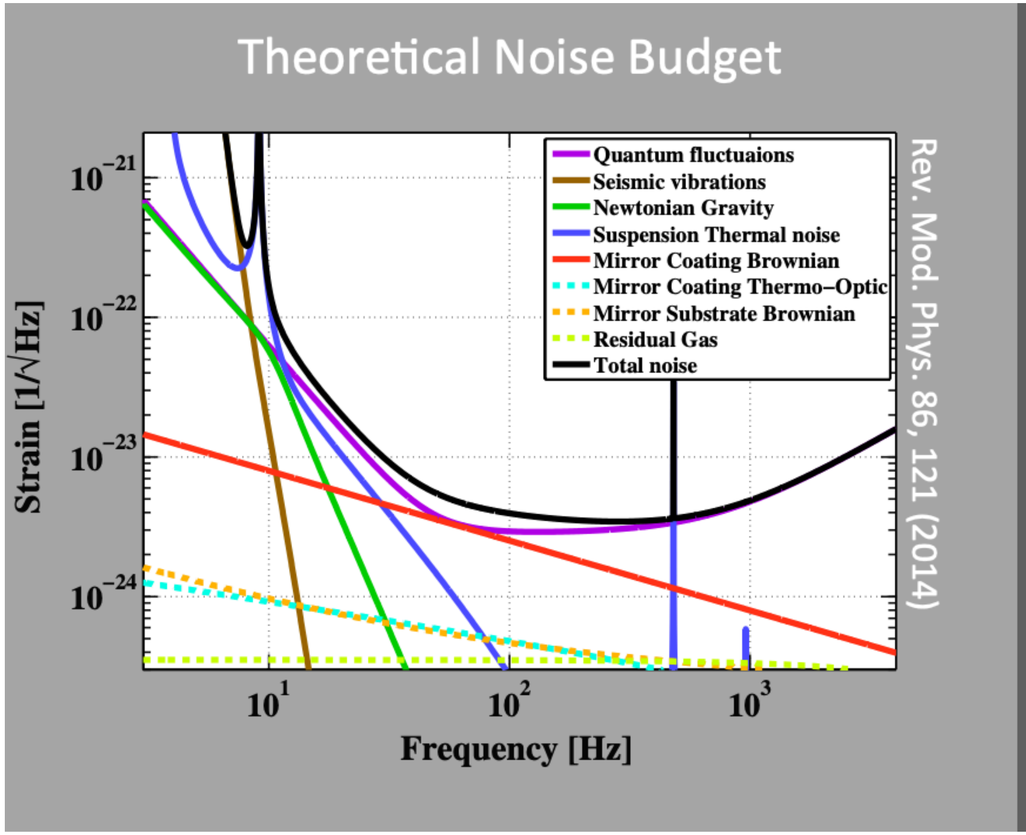


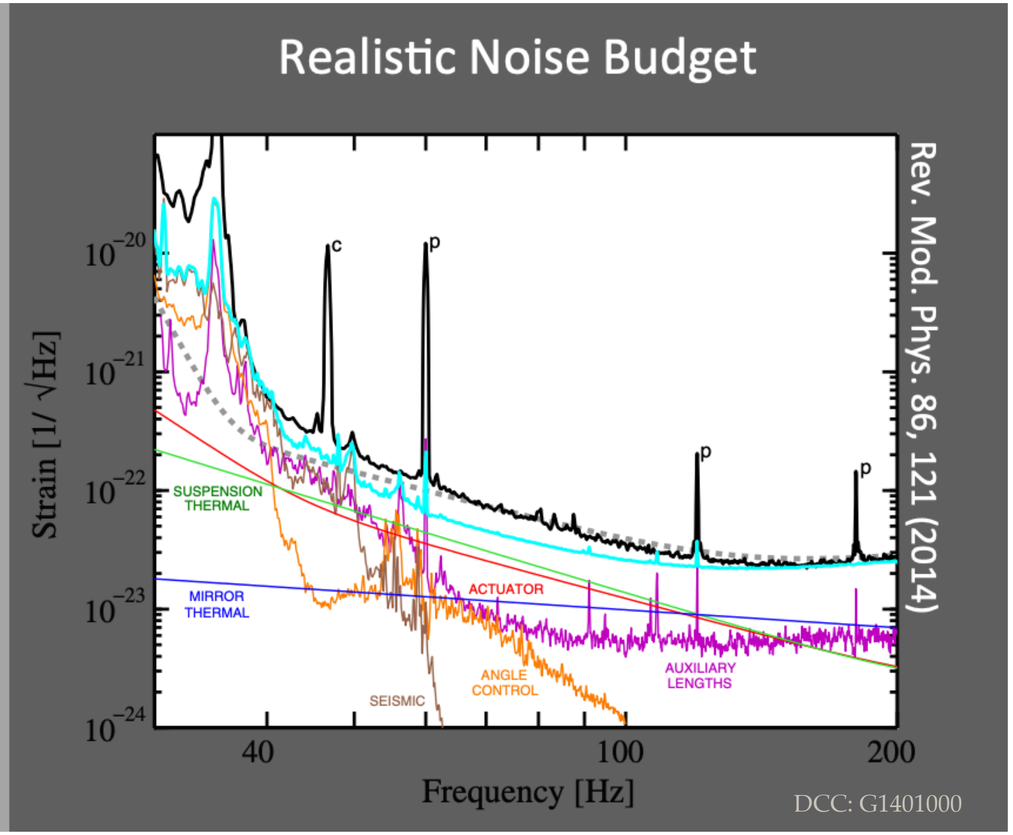
$$\Delta f \Delta t \geq 1/4\pi$$



The real data is more complicated

The noise is complicated and non-stationary



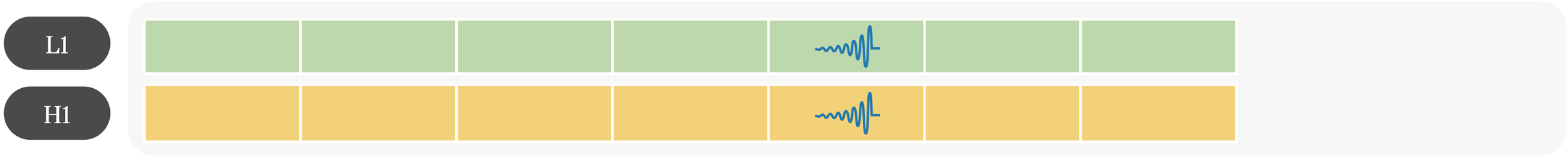


Find the coherence

The true signal should arrive in two detectors from the same sky location

Find the coherence

This is not enough because of the glitches



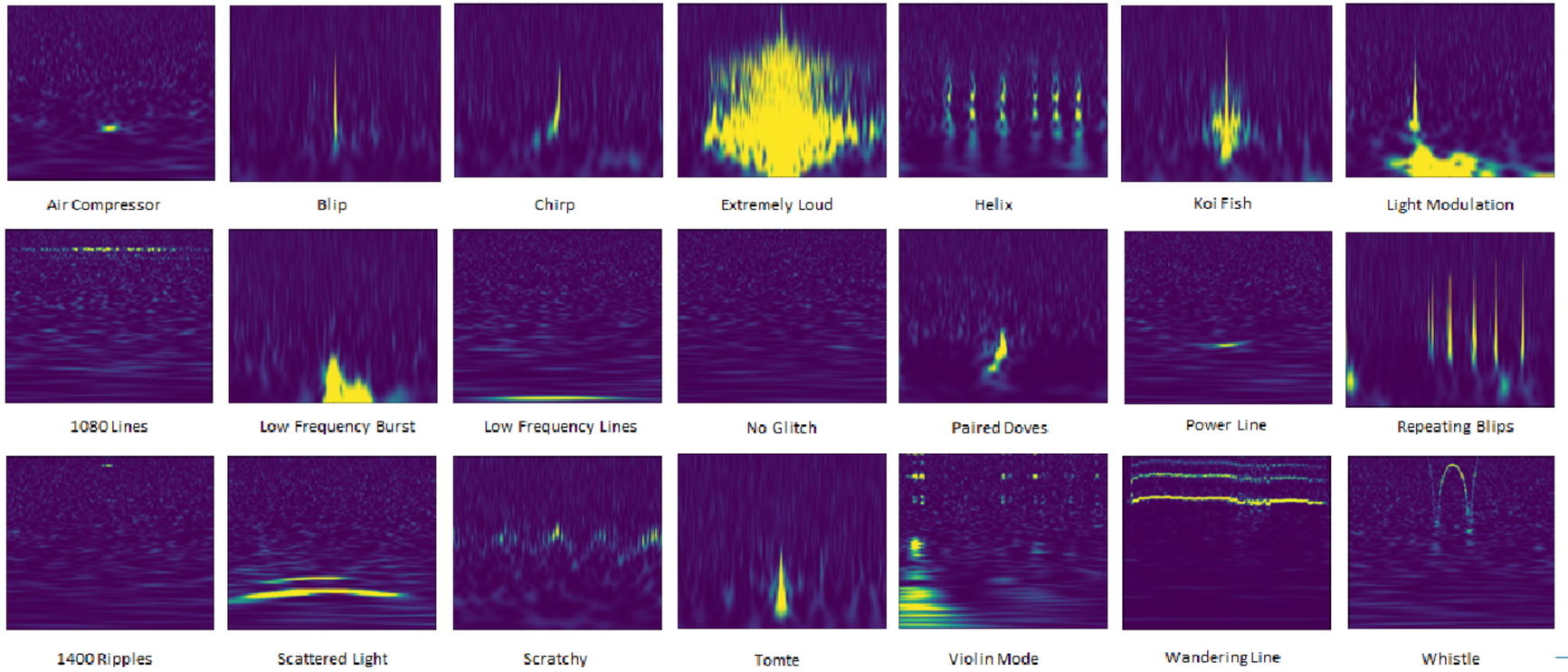


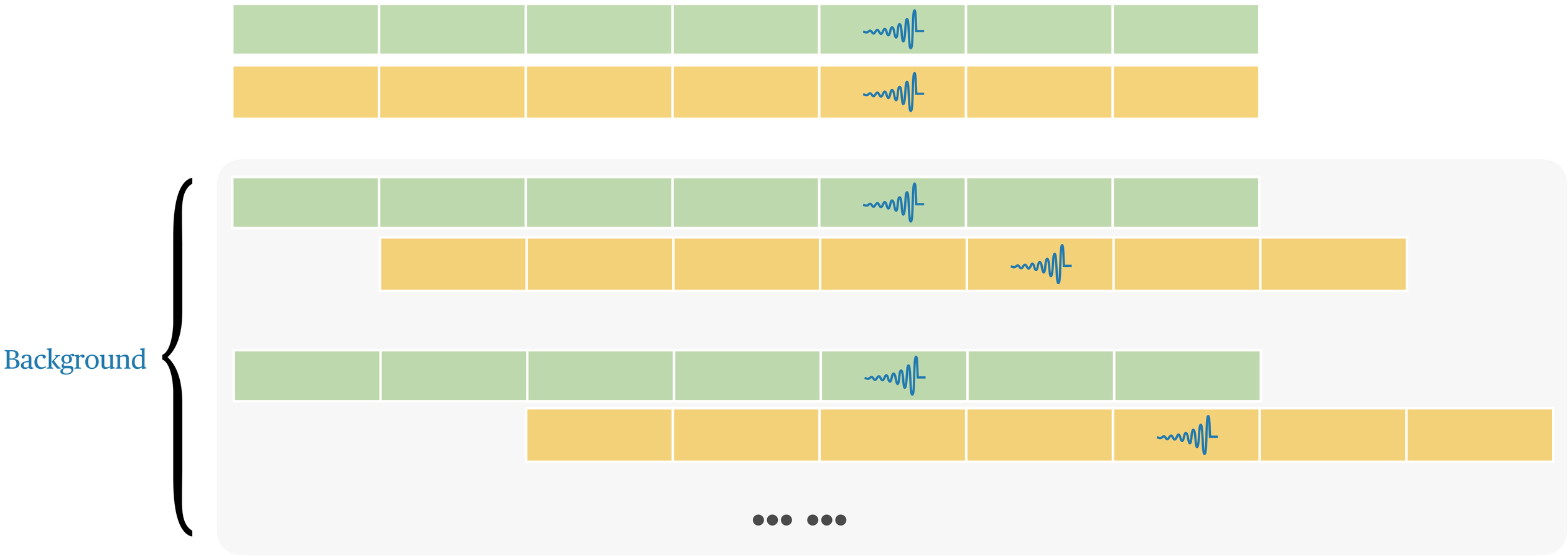
Figure 1: 2.0 second view of various types of glitches in the Gravity Spy dataset. None-of-the-Above glitch type excluded.

Find the coherence

Background Statistics

Find the coherence

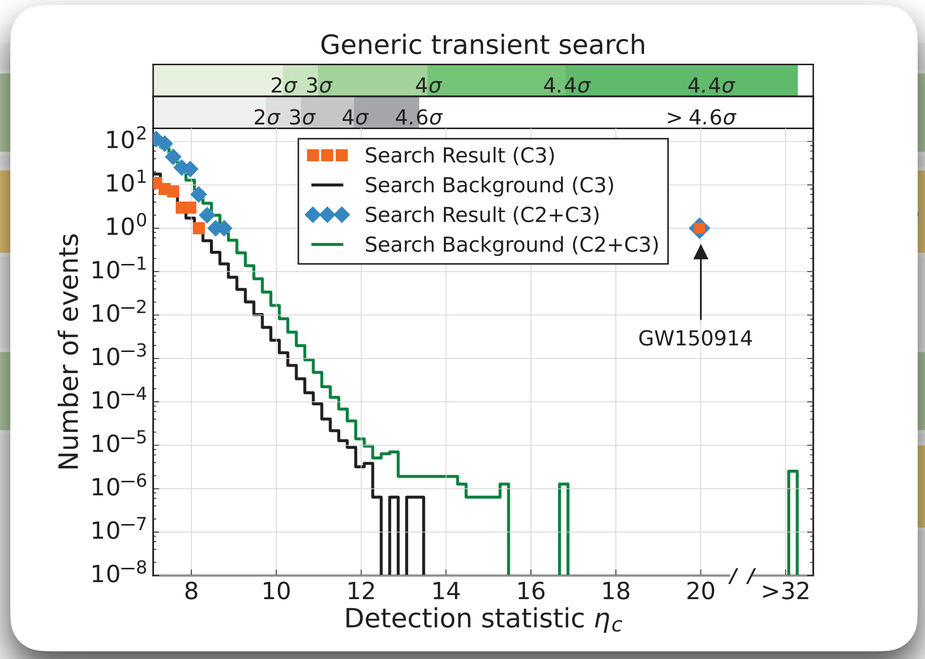
Background Statistics



Find the coherence

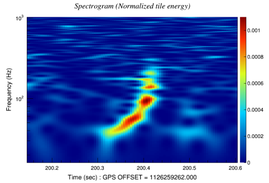
Background Statistics

Background

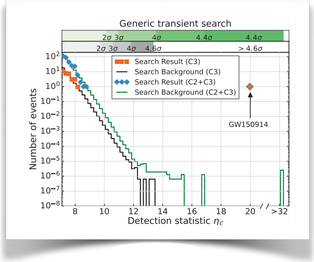


GW Strain from detectors

Trigger generation



Calculation of significance



Data Quality, validation

Environmental monitering

Source identification (paramaters)

Fundamental physics (Test of GR etc)

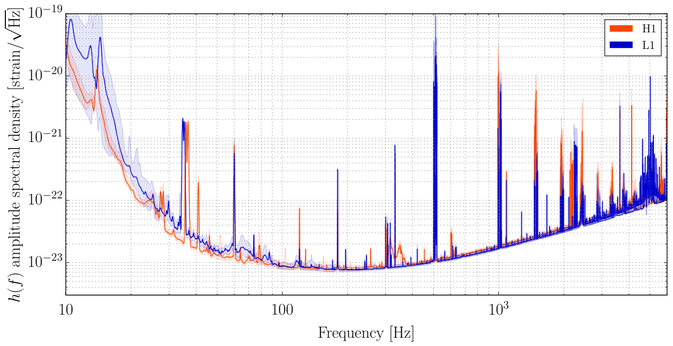
Astrophysics

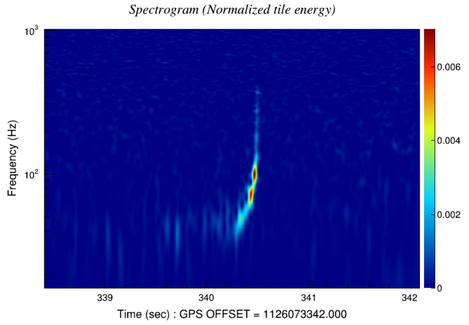
Rates

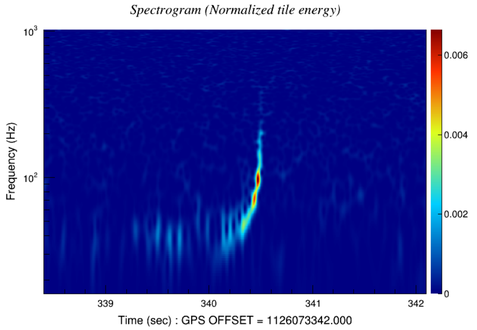
13

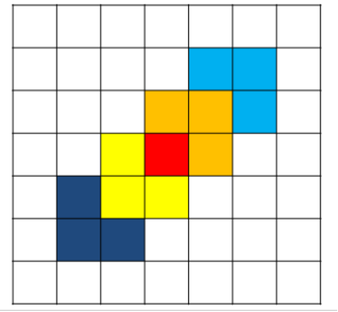
cWB : Un-modelled search schematic

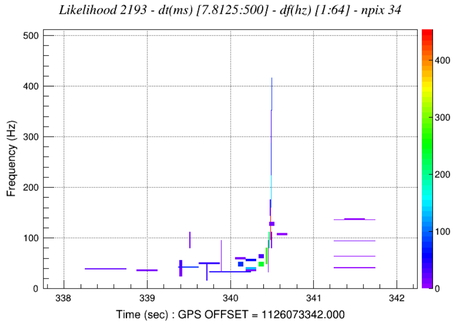
Read Data ····▶ Data conditioning ····▶ Time frequency transform and selection of pixels ····▶ Clustering and Superclustering ····▶ Likelihood analysis











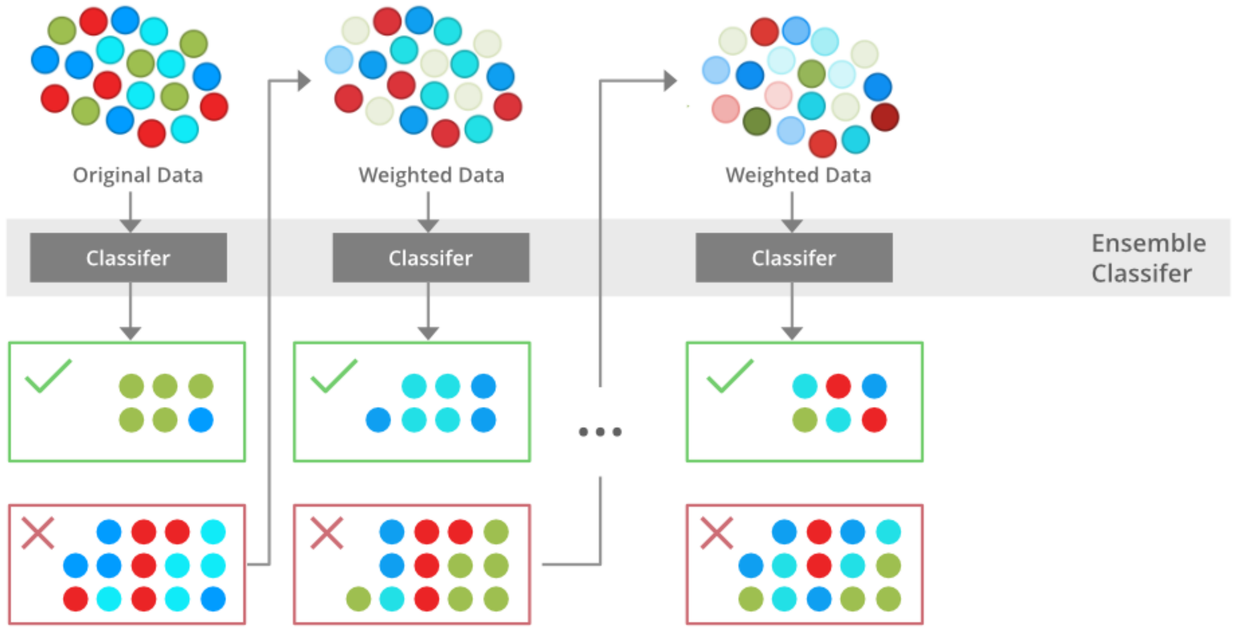
Improve the sensitivity with machine learning

Summary parameters for trigger:

- The effective correlated SNR
- Coherent energy
- Signal duration
- Signal bandwidth
- Signal central frequency
- The waveform shape parameter
- ...

High dimensional parameter space!

XGBoost as a classifier



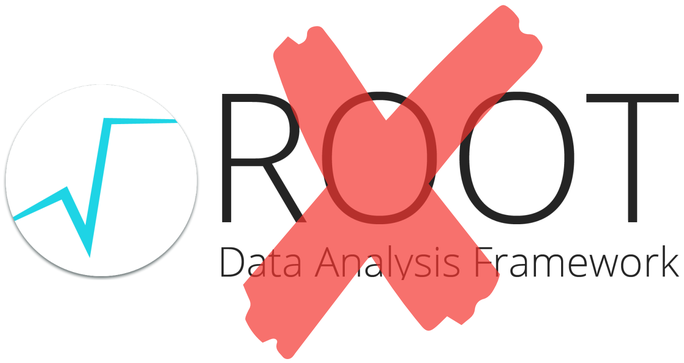
XGBoost Working | Source — https://www.geeksforgeeks.org/xgboost/

Potential for LISA

- Noise-agnostic and model-agnostic
- Low latency search
- Low computational cost
- Solve the overlap partially

Modernization of the framework: PycWB

pypi package 0.23.0



Monolith

Modular

SoftwareX, Volume 26, 101639, (05/2024) Yumeng Xu, Shubhanshu Tiwari, Marco Drago

Conclusion

- Time-frequency domain coherent search has performed very well in LIGO-Virgo search
- It has potential to migrate to LISA
- A lot of developments are needed for LISA

Acknowledgments

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