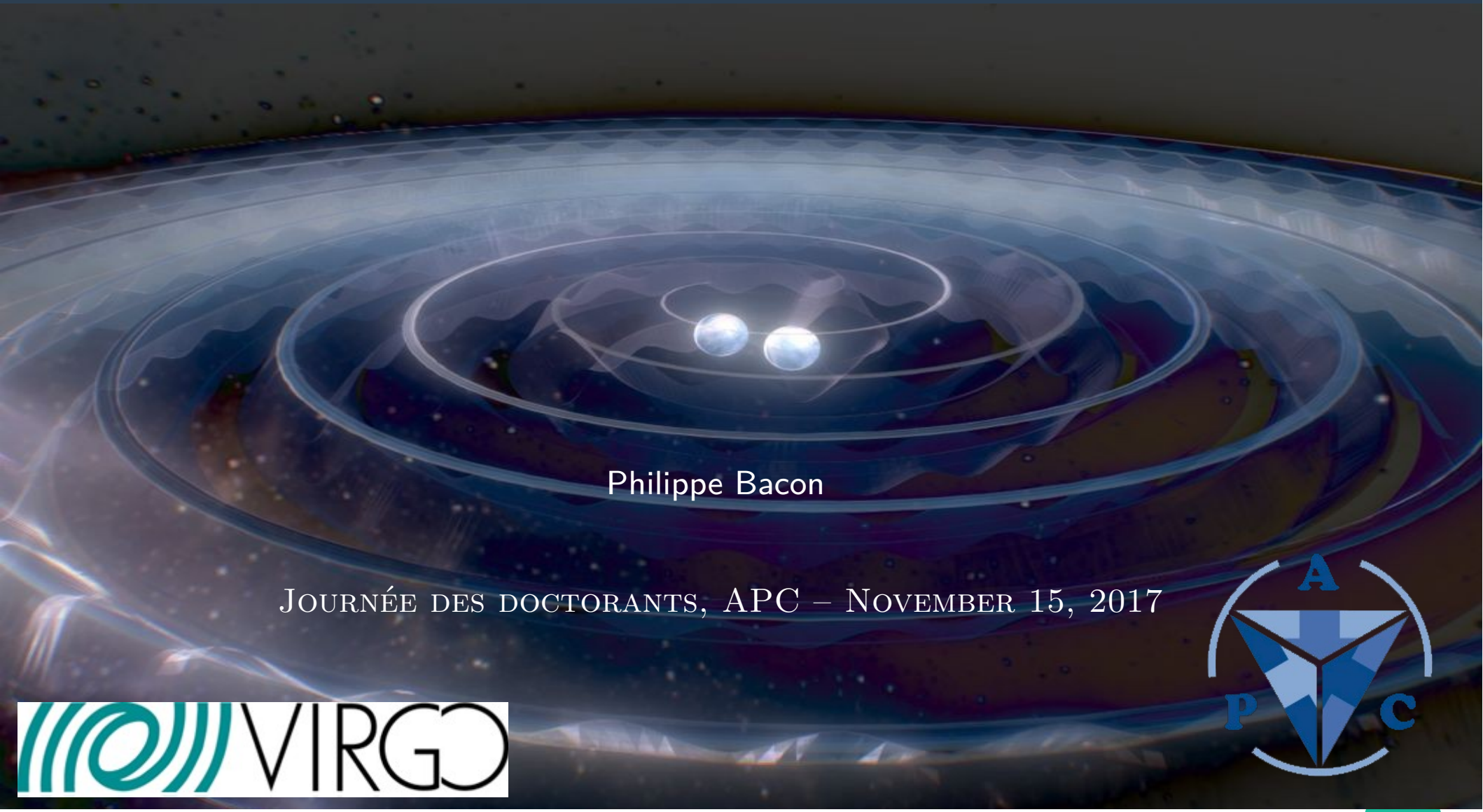
Wavelet-based search for gravitational wave detection



Philippe Bacon

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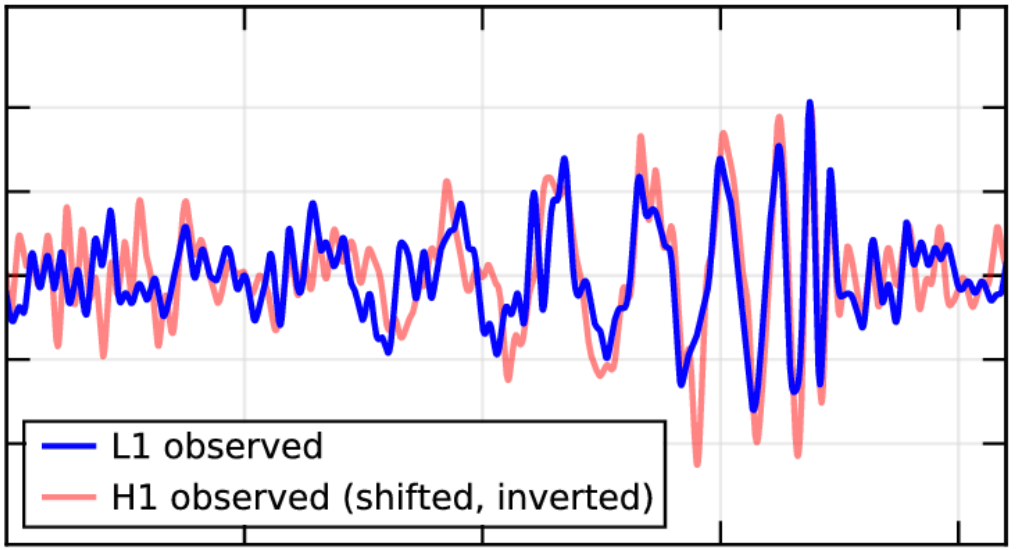
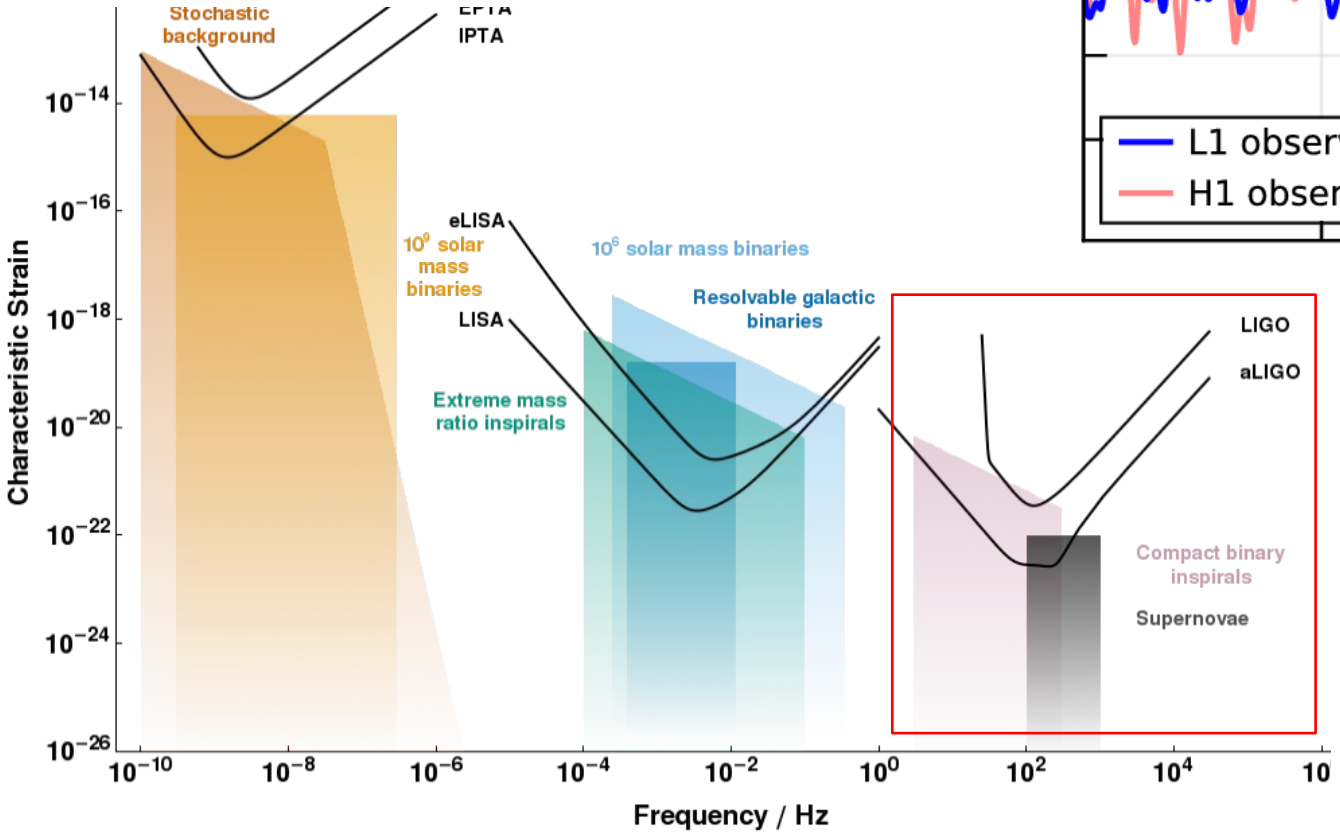
A new astronomy and a long history

Predicted a century ago ...

$$\Box \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu}$$





... and now detected !

$$h \sim \frac{\Delta L}{L} < 10^{-21}$$

Motivations

- Current modelled searches for compact binary mergers are based on the most likely astrophysical scenarios:

  Quasi-circular orbits, aligned spins, low mass ratio

  → But parts of this parameter space remain uncovered.
  This is where burst searches play a major role.

- Include higher order physical models in searches when available:

  Eccentricities, high mass ratios, precession

We present an informed burst search method potentially applicable to poorly investigated kinds of systems.
Demonstrated here with binary black hole systems.

On the software side of the Earth...

GW interact weakly with matter so the detector output is noisy :

How to find a rare transient with low signal to noise ratio ?

Expected signal is known.

Target search signature of compact binary mergers as predicted by general relativity.

Matched filtering

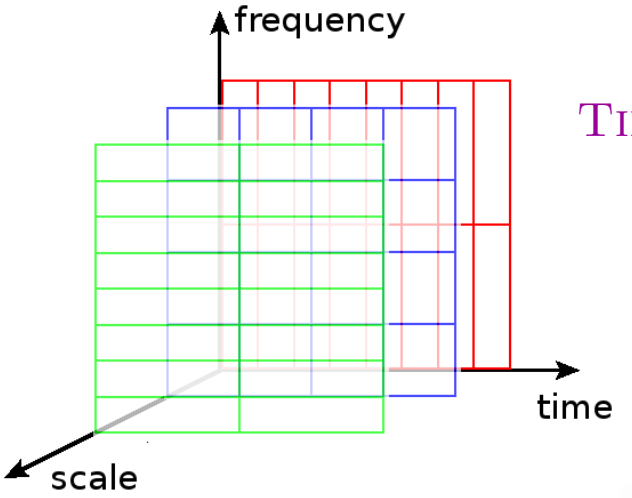
Expected signal is unknown.

Search transients appearing coherently in all detectors with no waveform prior.

Time-frequency excess power

CoherentWaveBurst

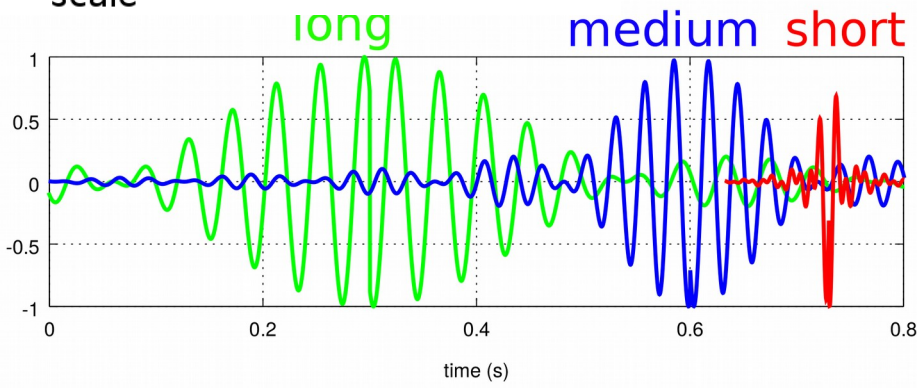
- Looks for excess power from GW transients signals.
- Uses Wilson transform on various time-frequency resolutions (=scales).

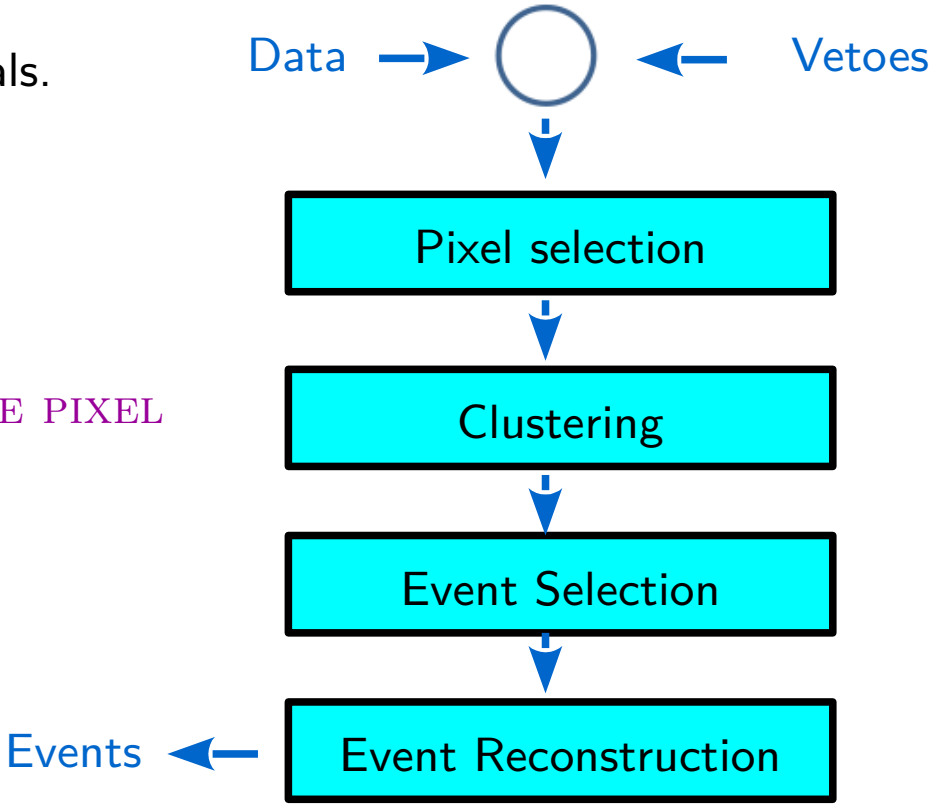


Time-frequency-scale pixel

=

wavelet

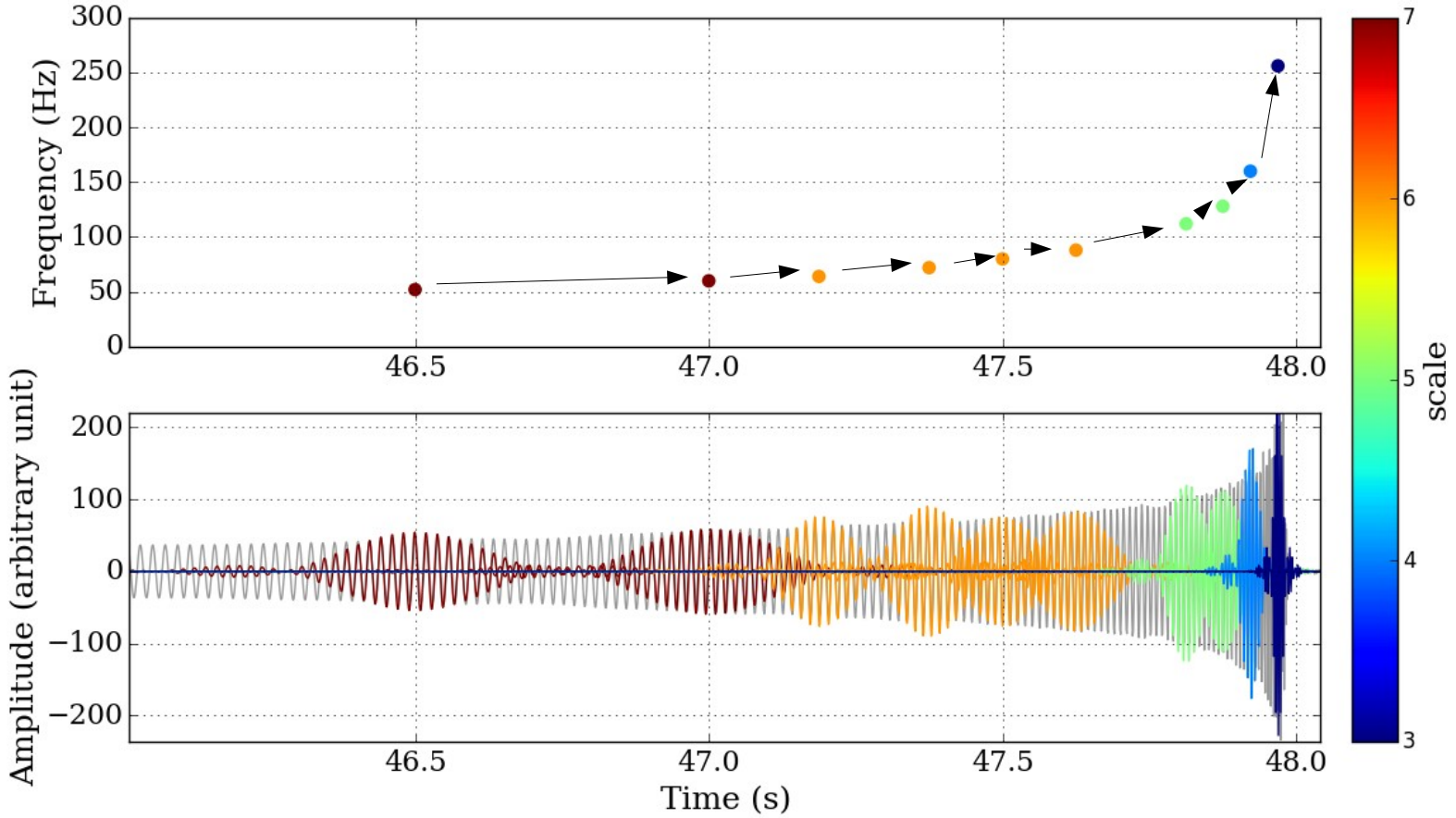




- Need for various resolutions to capture all signal patterns.
- Imposes constraints on cluster geometry at post-processing step.

Wavegraph basics – Pixel selection

- Map set of templates with chains of pixels through wavelet transform.
- Sparse representation of targeted signals ⇒ Pixel selection

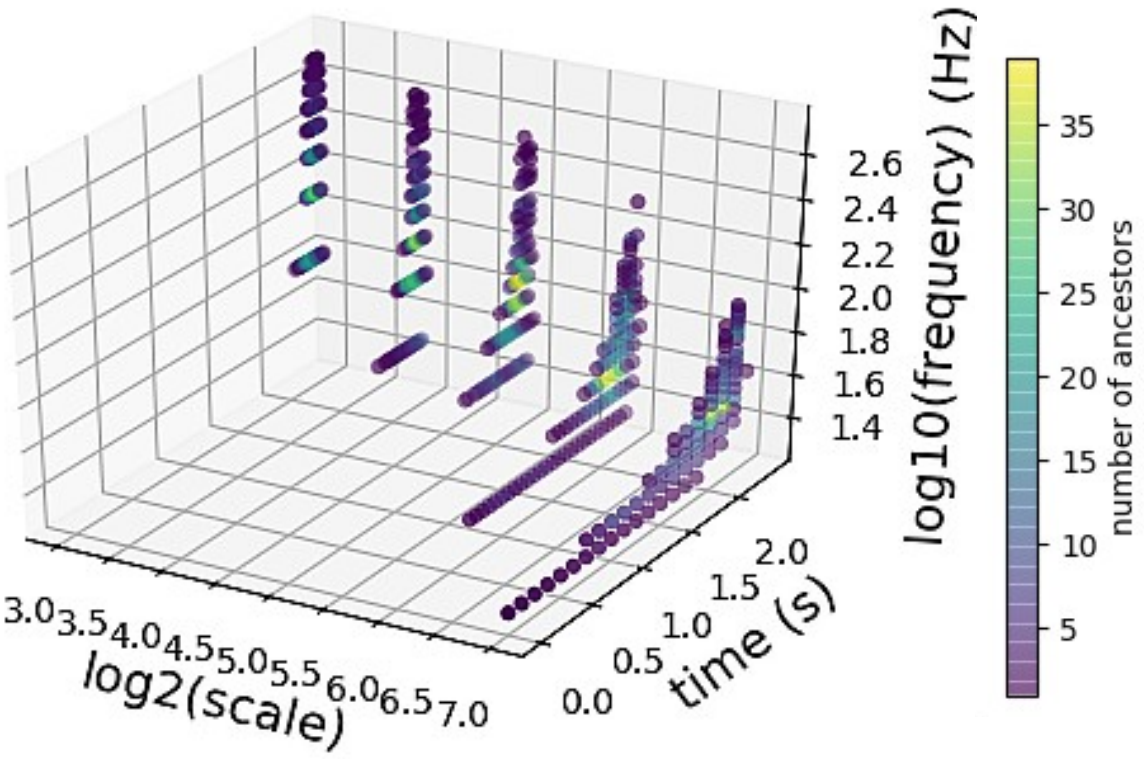


Binary black hole template

Wavegraph basics – Graph

Set of chains are formed by scanning over many templates.

Chains are combined to form a graph.



Parameter space for black hole binaries:

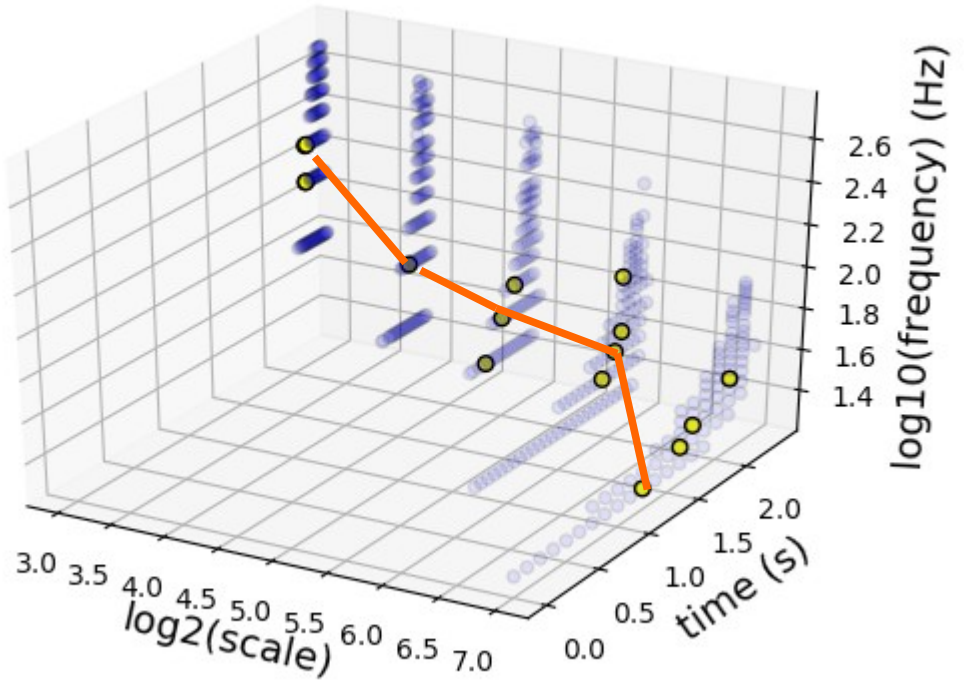
- Total mass: 40 – 70 $M_{\odot}$
- Full spin range: $|\chi_{1,2}| < 0.989$
- Mass ratio: $q_{max} \leq 2$

2950 templates in 533 pixels and their connections

→ Way of compacting prior information

Wavegraph basics - searches

Observational data h(t) are inserted into the graph.



Cluster of pixels extracted over the whole graph.

→ maximisation of the energy carried by the cluster.

Search for a cluster
is a longest path problem:
dynamic programming algorithm

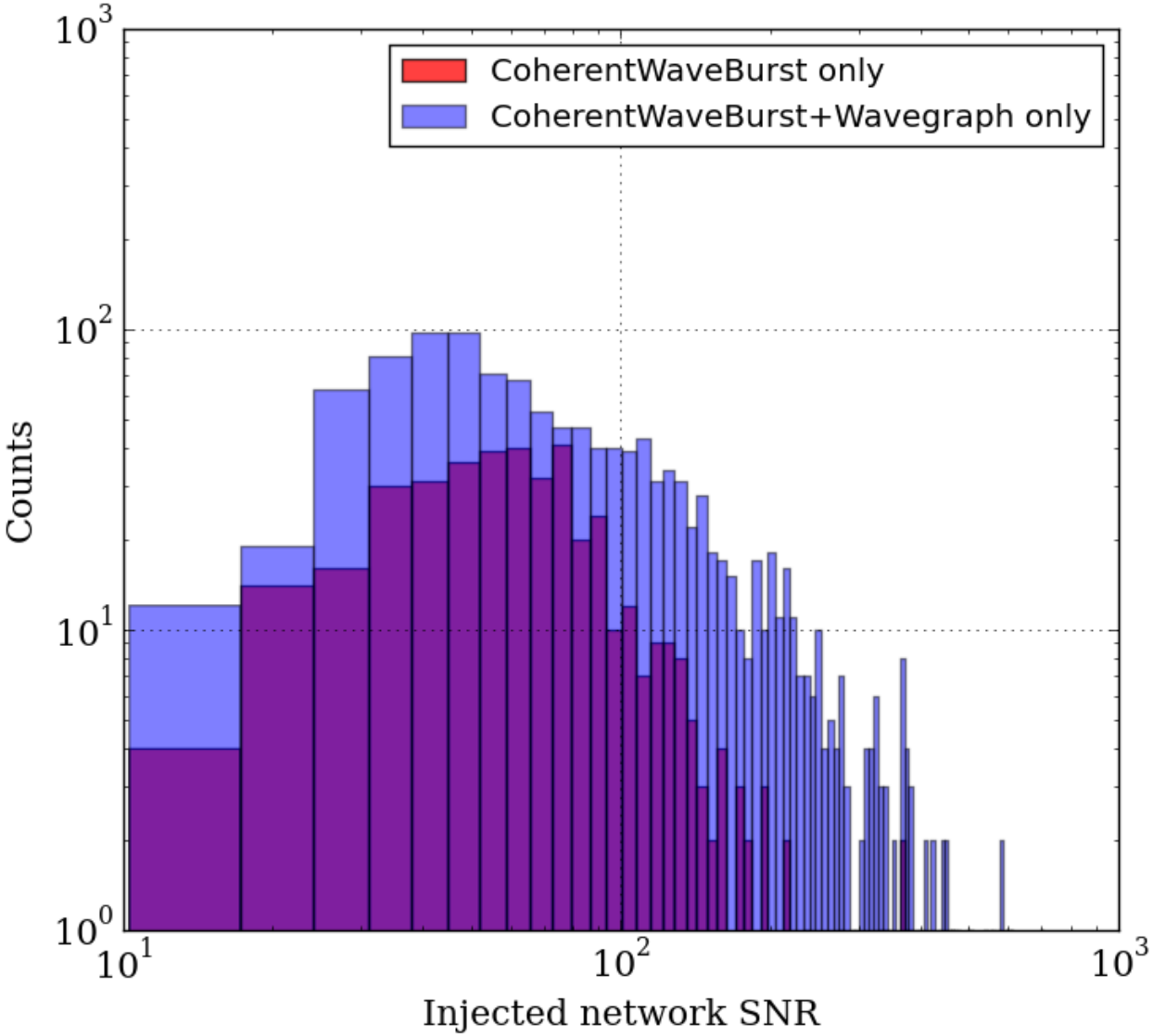
Mock Data Challenge presentation

Spinning binary black holes waveforms are injected into **Gaussian noise**.
(we used Spinning Effective One Body-Numerical Relativity waveforms)

Compare ability of CoherentWaveBurst and CoherentWaveBurst+Wavegraph to recover injections with advanced LIGO (H-L) and Virgo detectors (design sensitivity).

- SNR cuts fixed at fixed false alarm rate ($\sim$ 3 events / yr):
  - Signal coherence over interferometer network $c_c > 0.7$
  - Signal strength over network $\rho > 5.1$ for CoherentWaveBurst and $\rho > 5.2$ for CoherentWaveBurst + Wavegraph

Figure of merit: distribution of recovered injections



CoherentWaveBurst+Wavegraph is able to improve sensitivity in low injected SNR range despite more stringent cuts due to higher background.

Figure of merit: sensibility

CoherentWaveBurst
CoherentWaveBurst+Wavegraph

Injection set is compatible with the graph.

Relative improvement in effective range at FAR = 3 events / yr

Averaged over mass bins

Averaged number of injections over bins: ~ 90

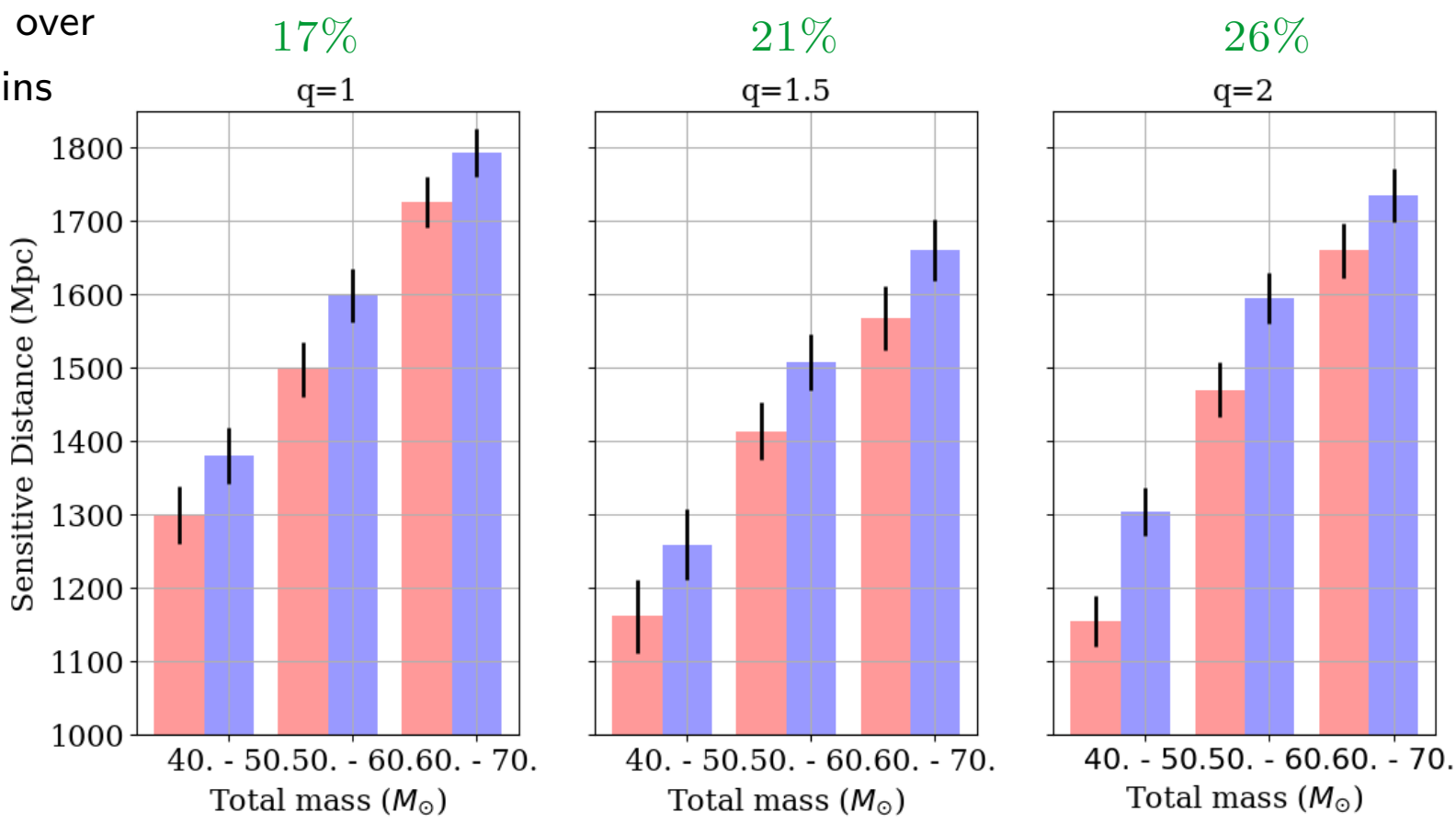
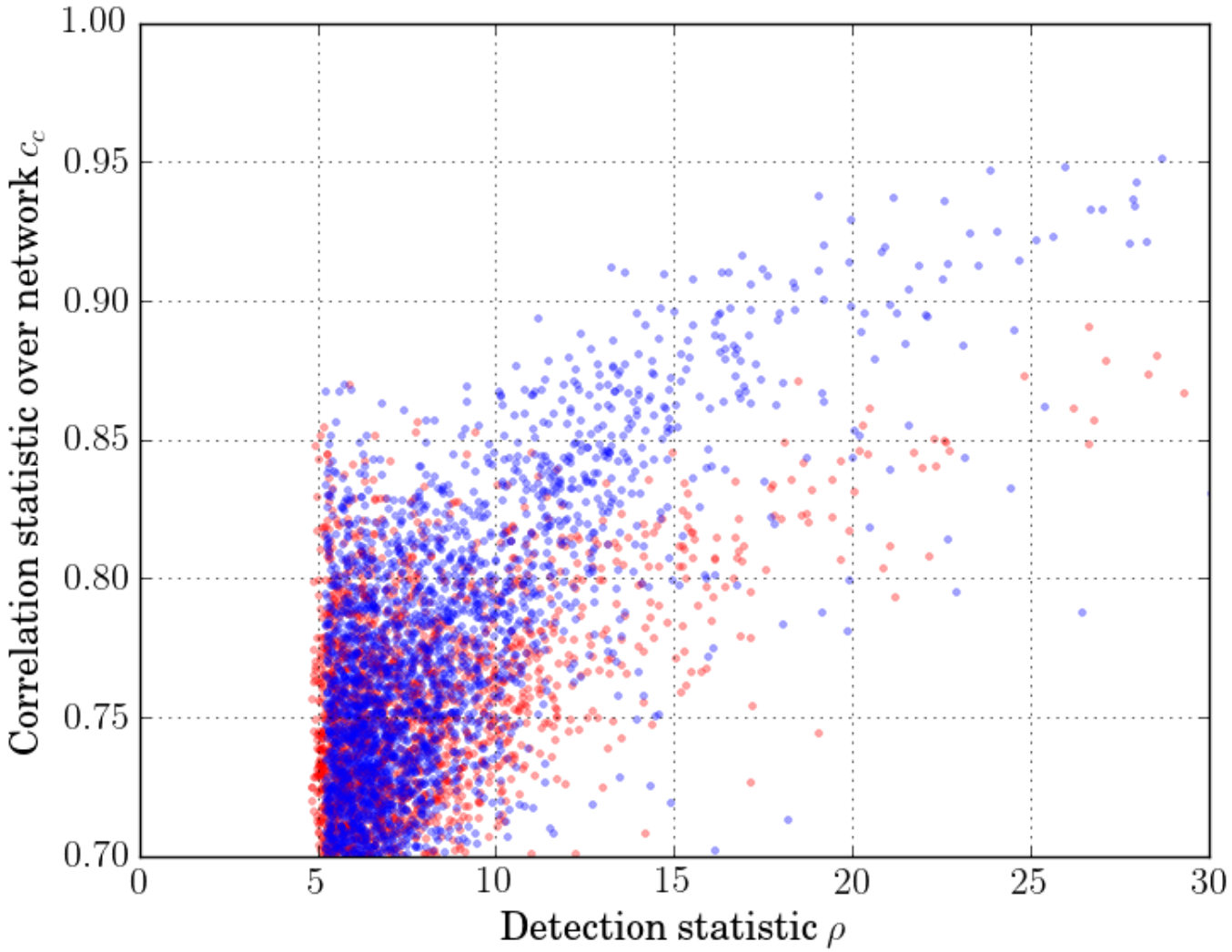


Figure of merit: correlation vs. detection statistic



Wavegraph extracts more relevant pixels wrt CoherentWaveBurst.

On average these signals are more correlated between detectors.

Conclusion

- **Wavegraph** is a new clustering scheme dedicated to CoherentWaveBurst whose aim is to include astrophysical waveform models in burst searches.

- For binary black hole waveforms, Wavegraph shows better sensitivity (until 25% improvement in visible volume) in the 40 – 70 $M_\odot$ range with Gaussian noise.

  Results using real data will strongly depends on glitch rejection: preliminary results.

  Pixels selected by Wavegraph have a larger correlation between detectors.

- Graph generation can potentially be generalized to other kinds of systems.

  - Implementation of high eccentricity burst model for waveform generation.
  - Apply Wavegraph to search for moderately eccentric systems.