Enhancing un-modelled gravitational wave searches

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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.

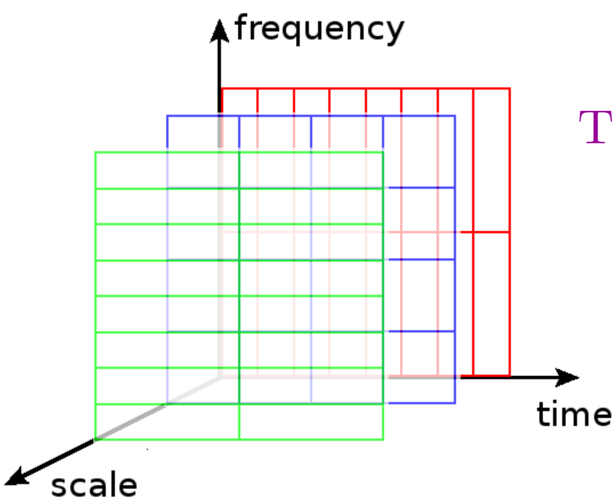
- Include higher order physical models in searches when available:

  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.

Coherent WaveBurst [1]

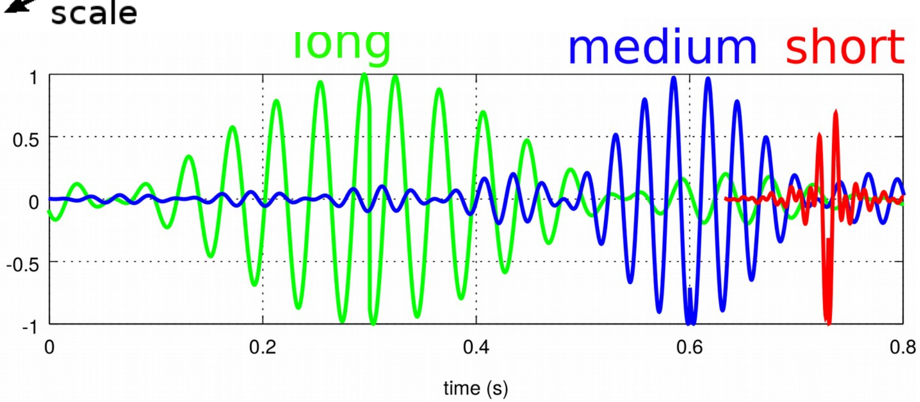
- Looks for excess power from GW transients signals.
- Uses Wilson transform at different time-frequency resolutions (= scales).

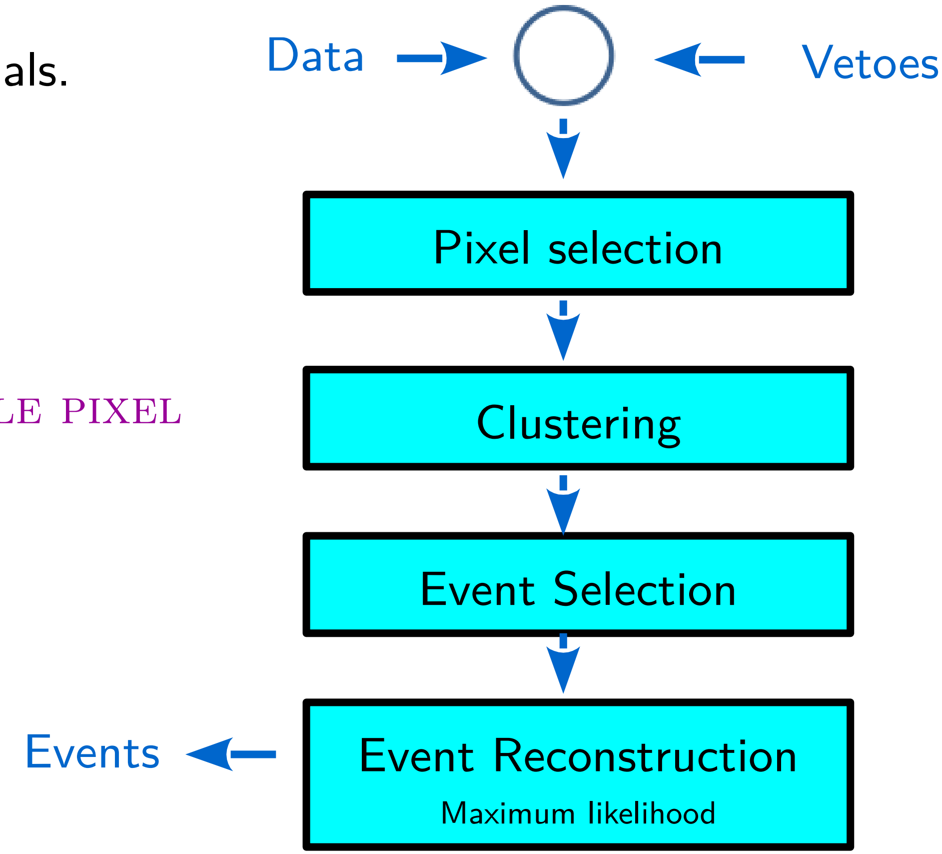


Time-frequency-scale pixel

=

"wavelet"



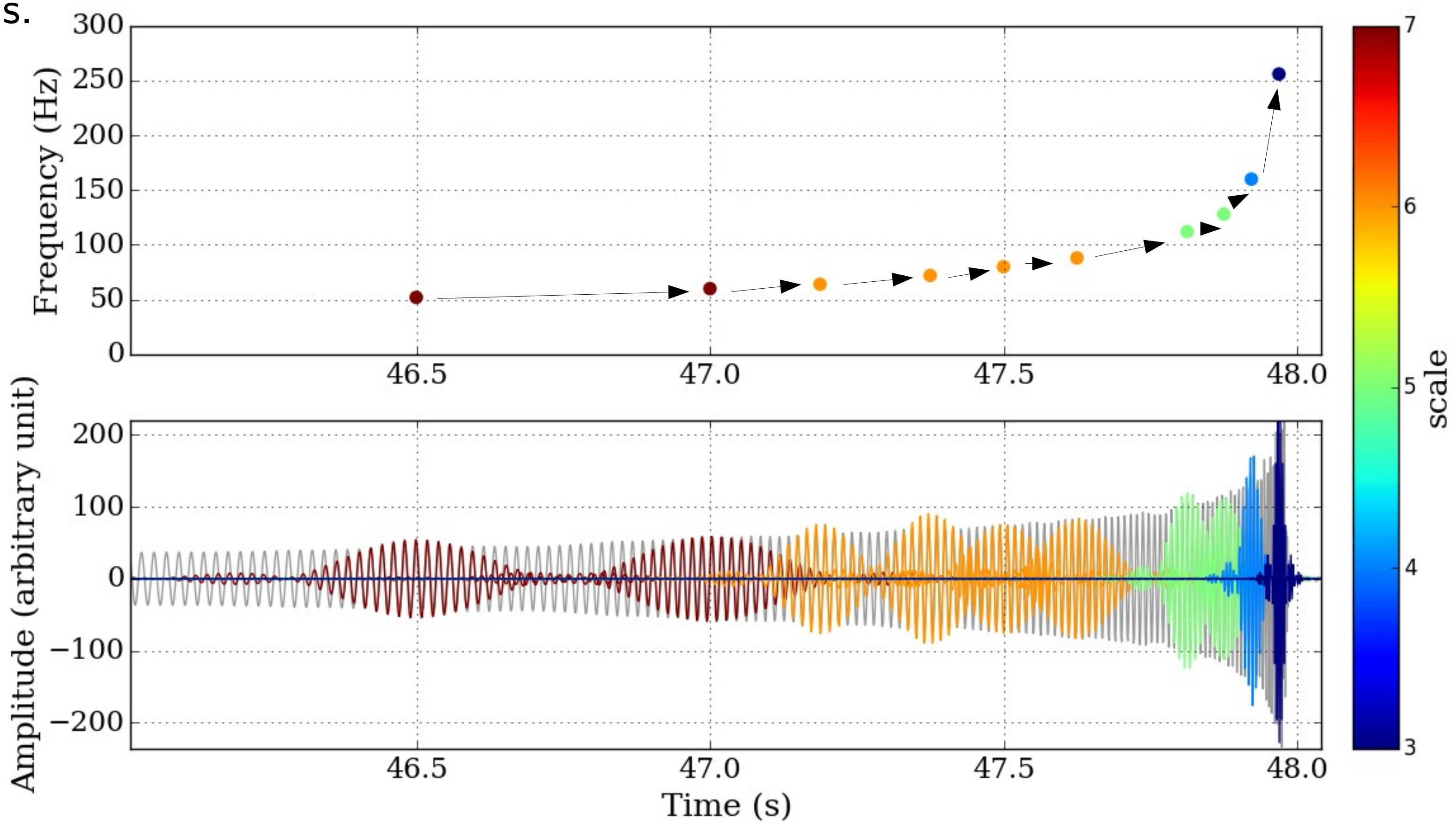


- Need for various resolutions to capture all signal patterns.
- Imposes constraints on cluster geometry at post-processing step.

[1] Klimenko et al Phys. Rev. D 93, 042004 (2016)

Wavegraph basics – Pixel selection

- Map waveform template to a chain of time-frequency pixels.
- Selection of representative time-frequency pixels from sparse representation of targeted signals.

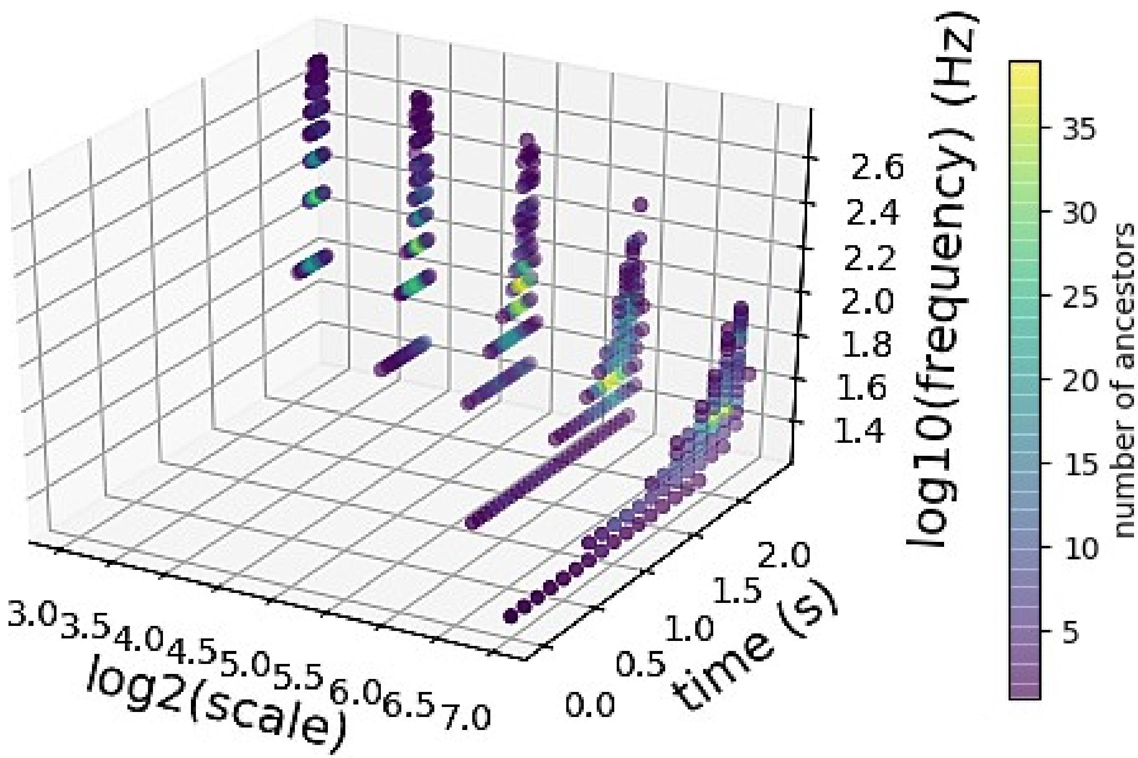


Example with a Binary black hole template

Wavegraph basics – Graph

Obtain set of pixel chains from many templates that sample the parameter space

Chains are combined into a graph

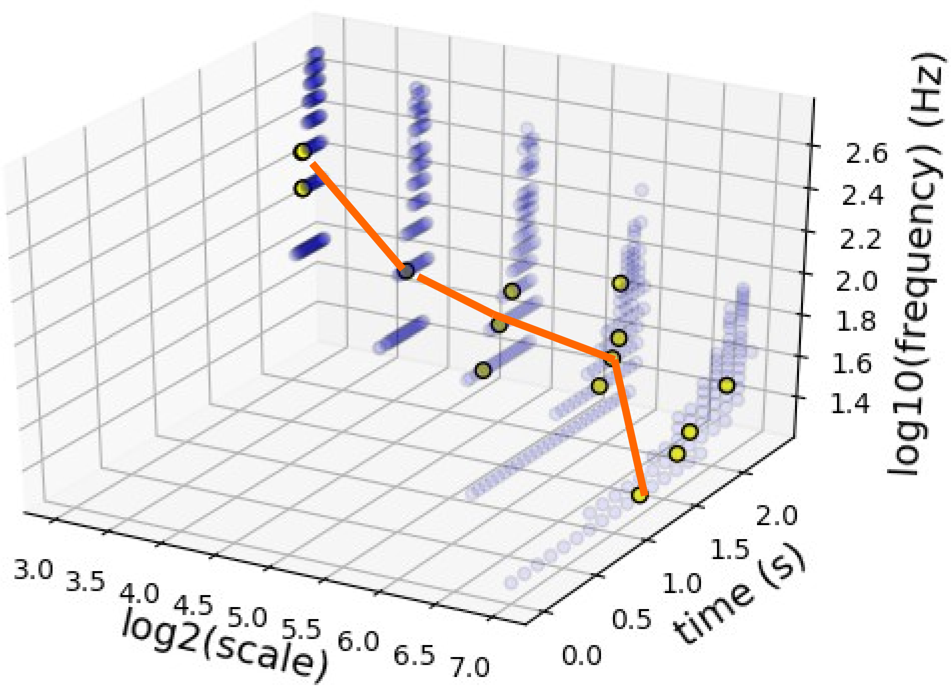


Parameter space for black hole binaries:

- 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" the information in the waveform model



Time-frequency pixel obtained from 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

18,000 binary black hole waveforms

using Spinning Effective One Body-Numerical Relativity model [1]

Isotropically distributed and uniform in volume

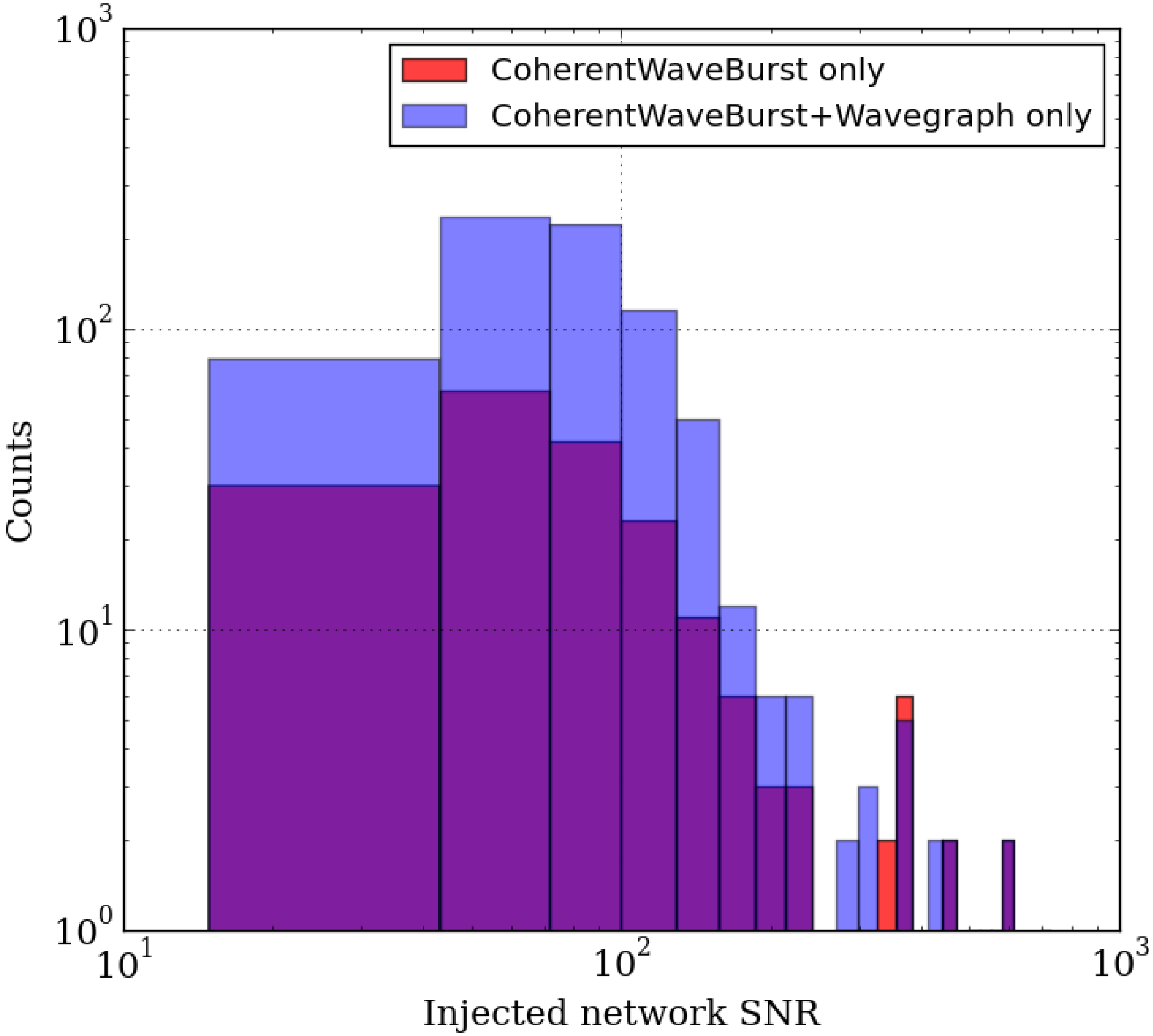
Mass range compatible with search graph

Compare ability of CoherentWaveBurst (current version used for LIGO O2 run) and CoherentWaveBurst+Wavegraph to recover injections in simulated **Gaussian noise** for advanced LIGO (H-L) and Virgo detectors at design sensitivity.

- Selection 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 Coherent WaveBurst + Wavegraph

[1] A. Taracchini et al, Phys. Rev. D, 89(6):061502:1–6, 2014

Review of missed and recovered injections



Recovered injections:

by CoherentWaveBurst ~2140,

when using Wavegraph ~2600 (+20 %)

Distribution of injections detected by one algorithm and missed by the other

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

Average sensitive range

CoherentWaveBurst

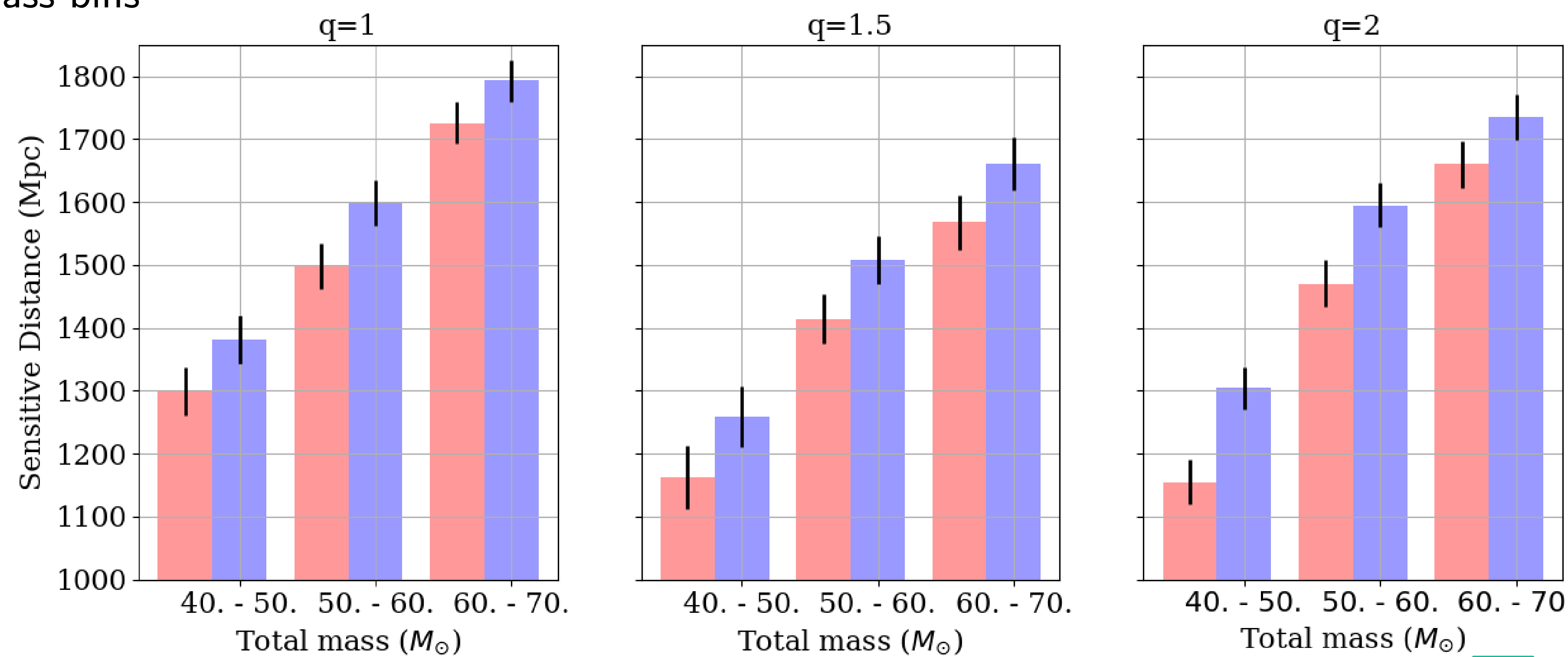
CoherentWaveBurst+Wavegraph

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

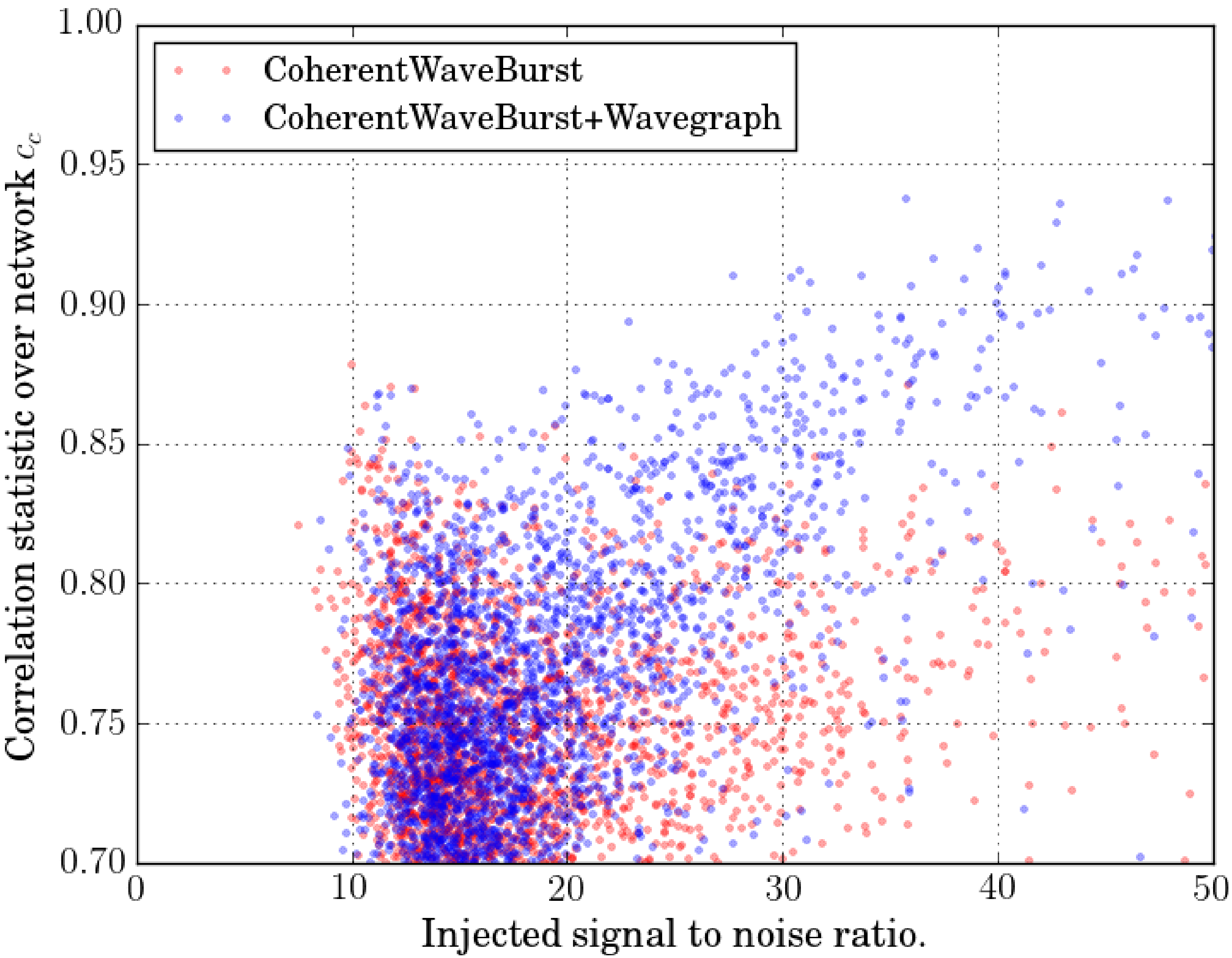
Averaged over mass bins

6% 7% 8%

Averaged number of injections over bins: ~ 90



Correlation vs. injected SNR



Wavegraph extracts more relevant pixels with respect to CoherentWaveBurst.

Selected pixels are less likely associated to nearby noise fluctuations, and have thus a larger overall correlation between detectors.

Conclusion

- **Wavegraph** is a new pixel clustering scheme dedicated to Coherent WaveBurst

  Drive pixel selection using astrophysical waveform models

- For binary black holes, Wavegraph enhances the sensitive reach; ~20-25 % in detection rate

  Pixels selected by Wavegraph have a larger correlation between detectors

- Caveat: preliminary! Results obtained using Gaussian noise

  Results using real data will strongly depends on glitch rejection

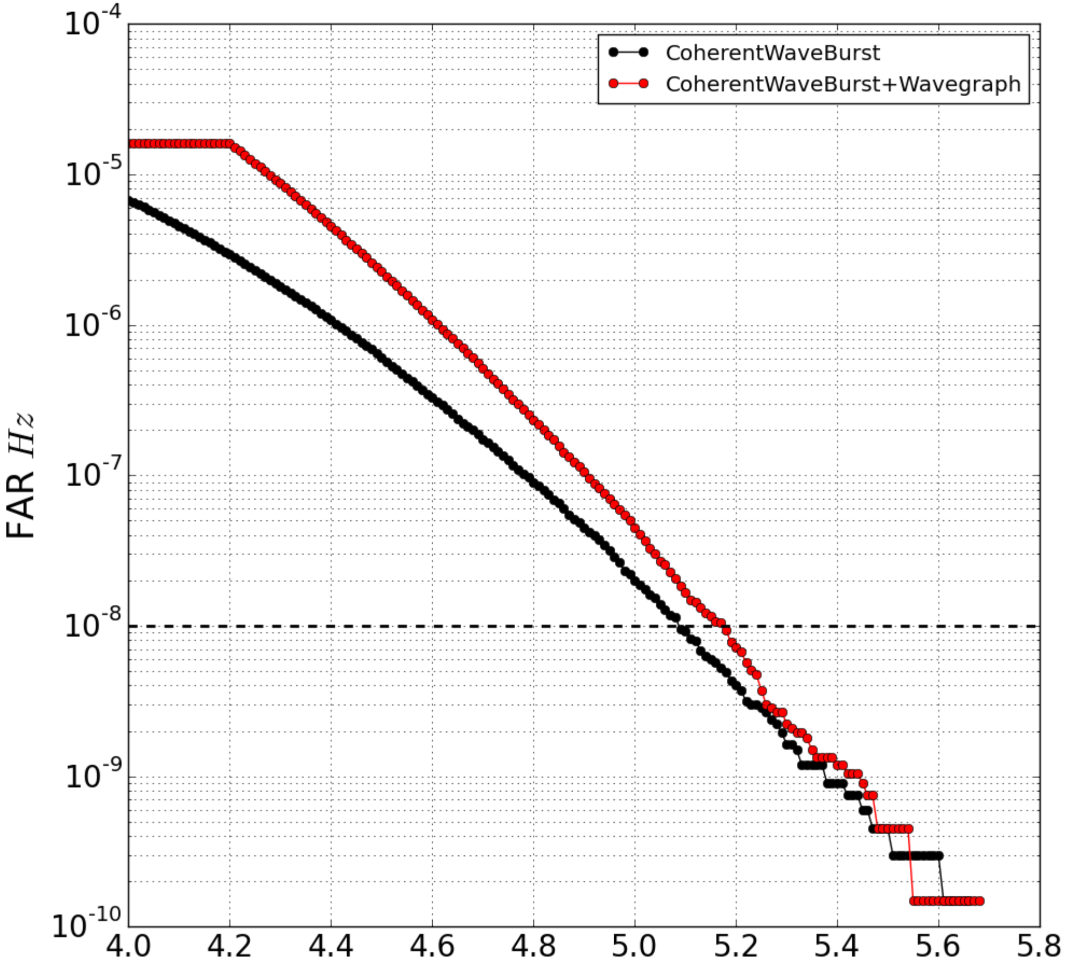
- Graph generation can potentially be generalized to other kinds of systems

  - Plan to apply Wavegraph to highly eccentric binary systems

BACKUP SLIDES

$>$ BKG: CWB & WG
$>$ Recovered injection - example
$>$ CWB in a nutshell
$>$ Demonstration of Matching pursuit.

Backgrounds

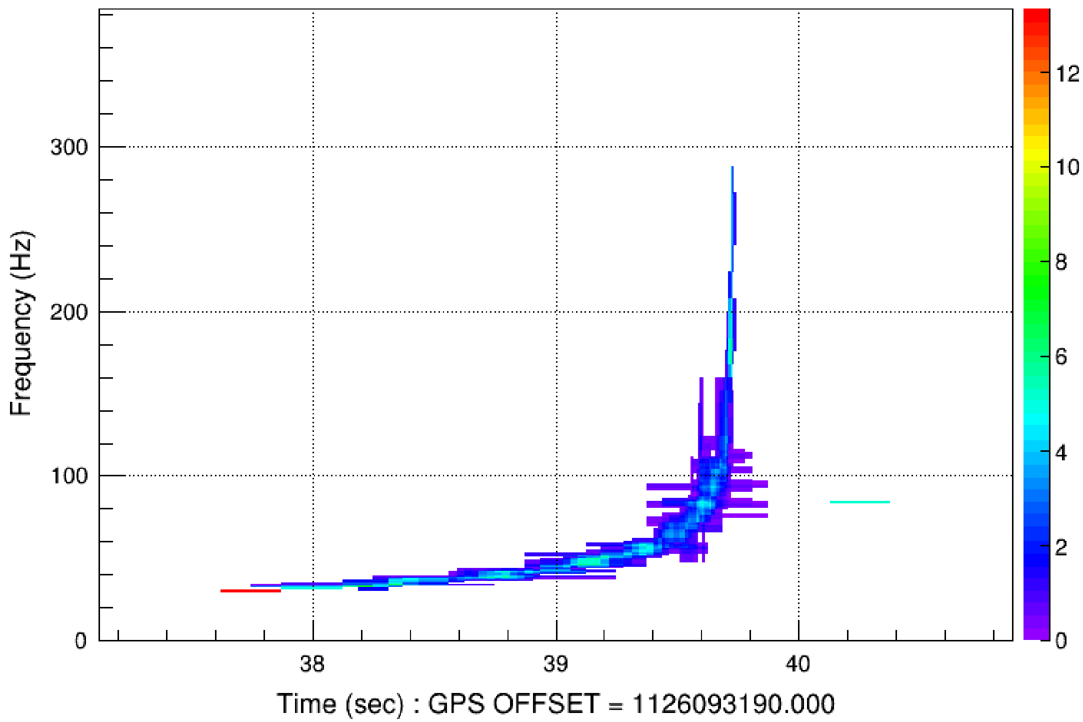


Detection statistic ρ

Recovered injection - example

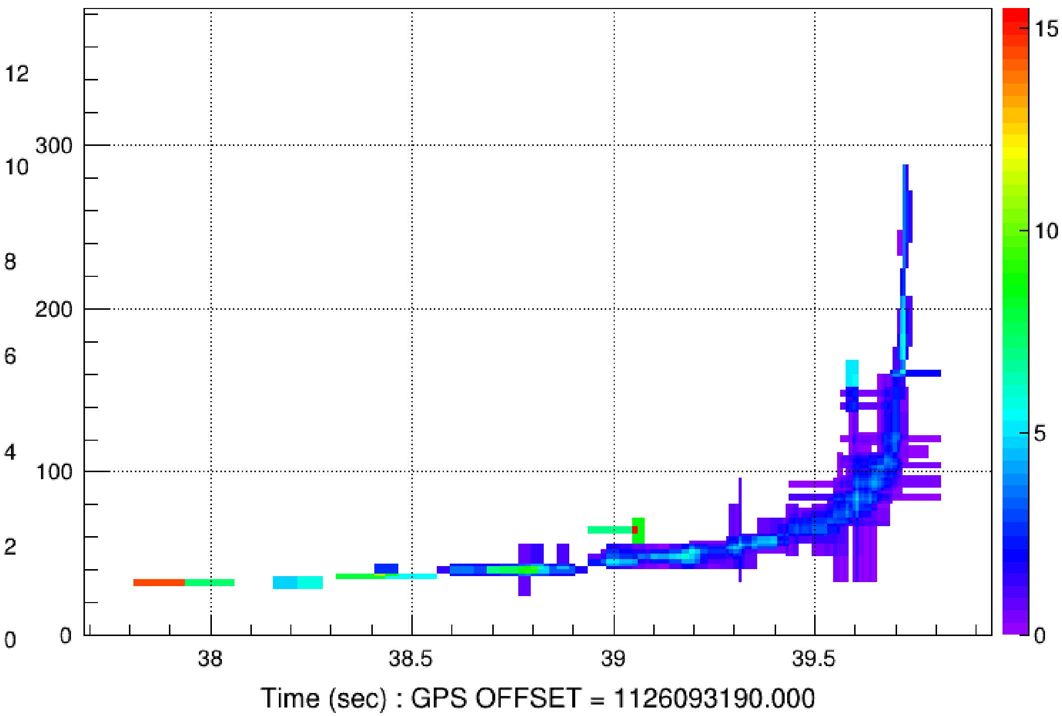
Injected sNR = 26

Reconstructed SNR = 28.8



CWB (167 pixels)

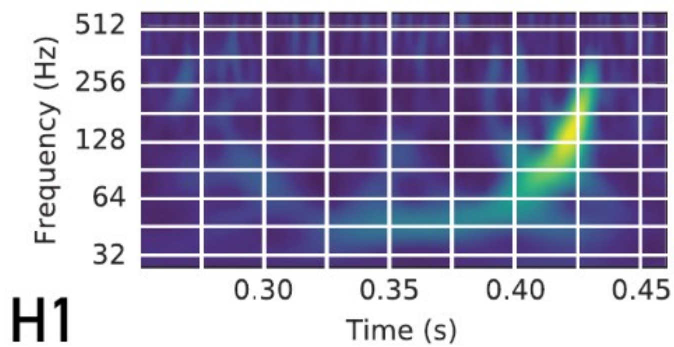
Reconstructed SNR = 30.1

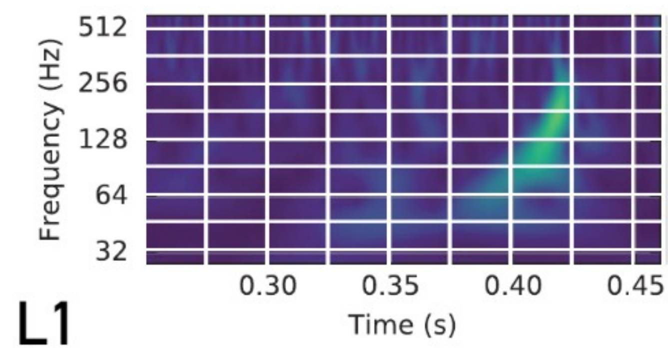


CWB+WG (171 pixels)

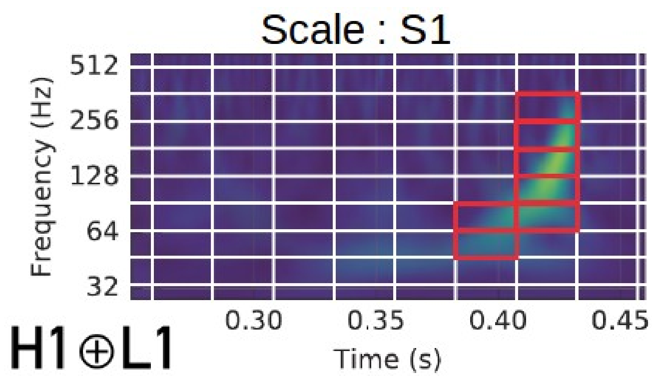
CoherentWaveBurst

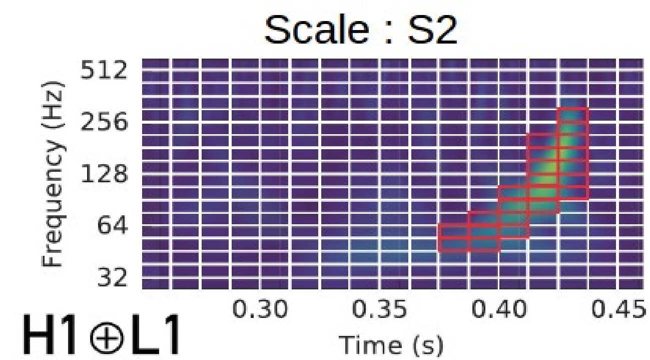
CWB TF grid



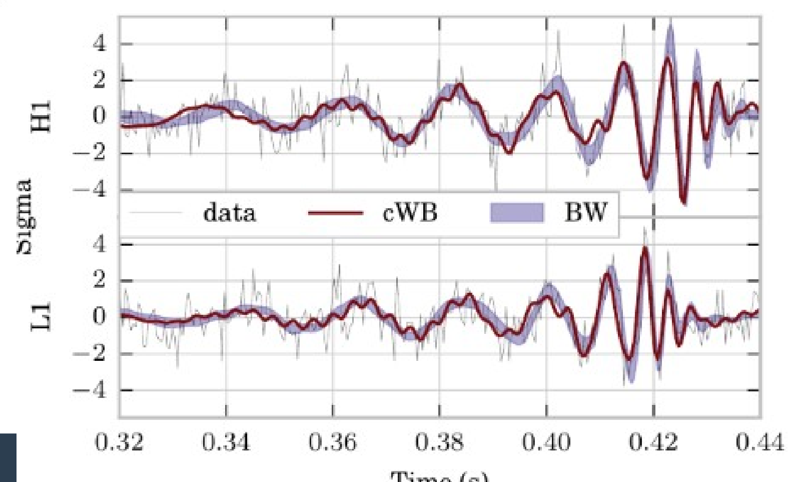


Collecting excess power pixels.



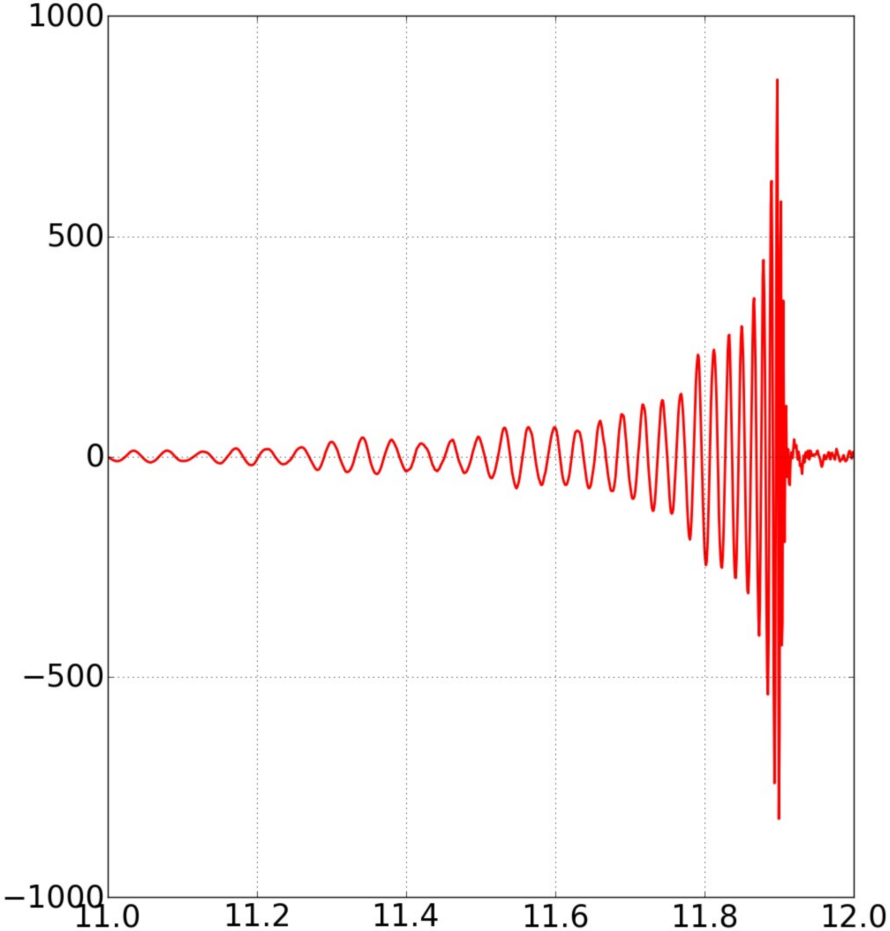


Reconstructing waveforms

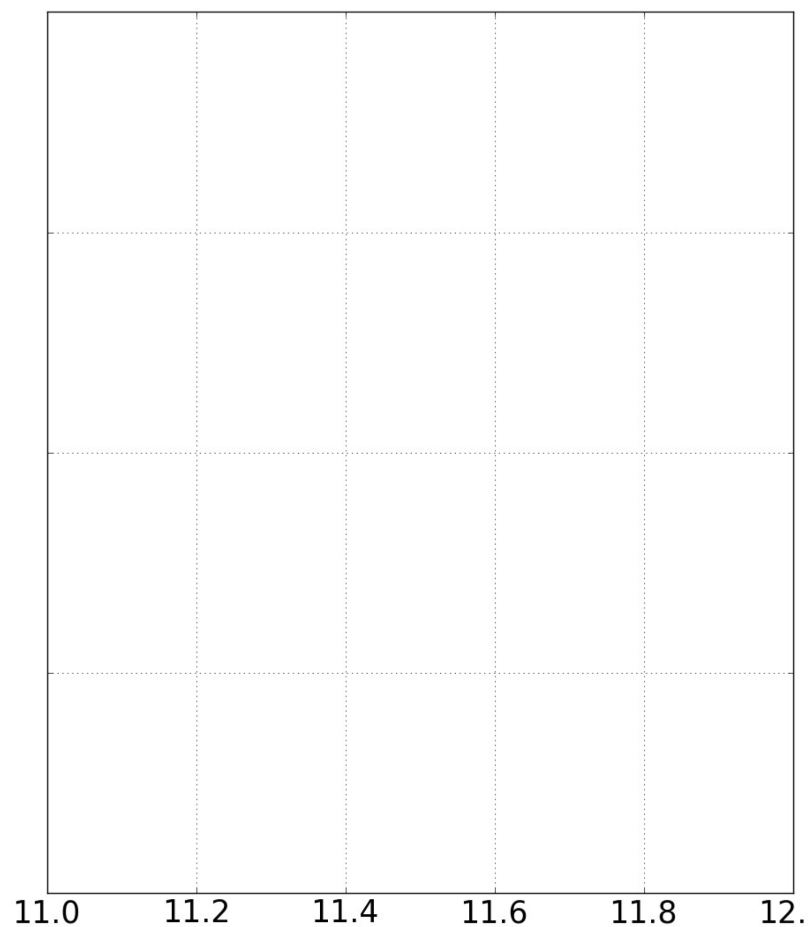


LVC, PRL D, 116, 061102 (2016)
LVC, arXiv 1602.03843 (2016)

Matching pursuit : 0^{th} iteration

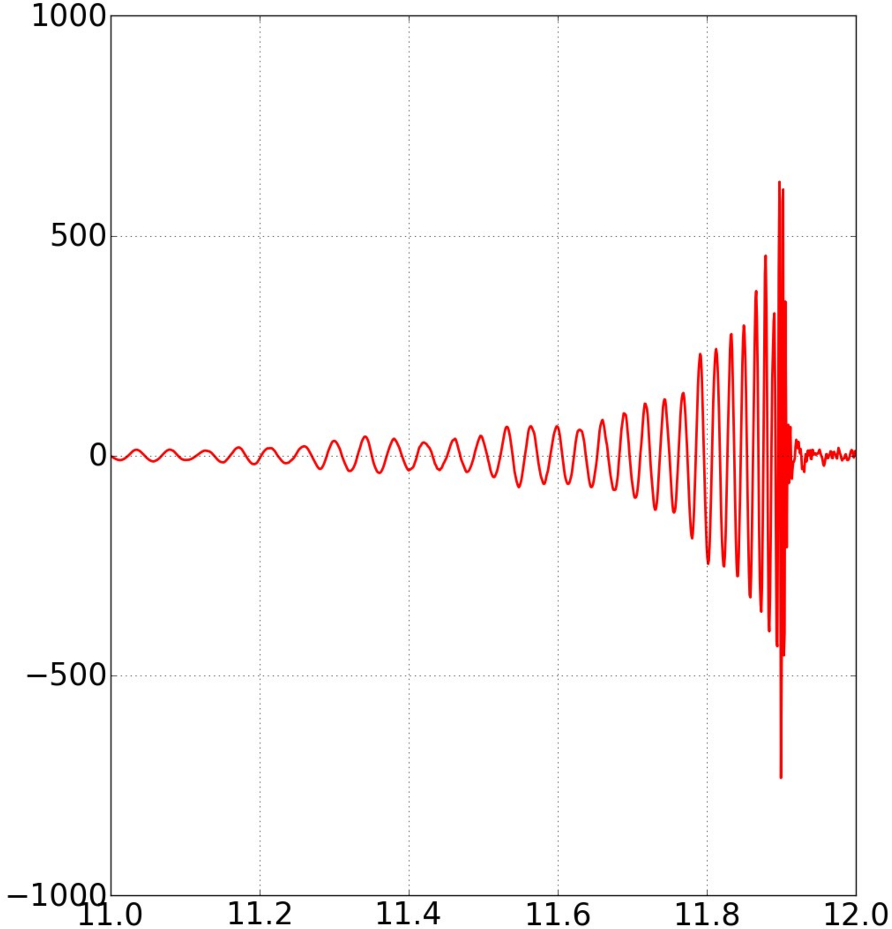


Residue

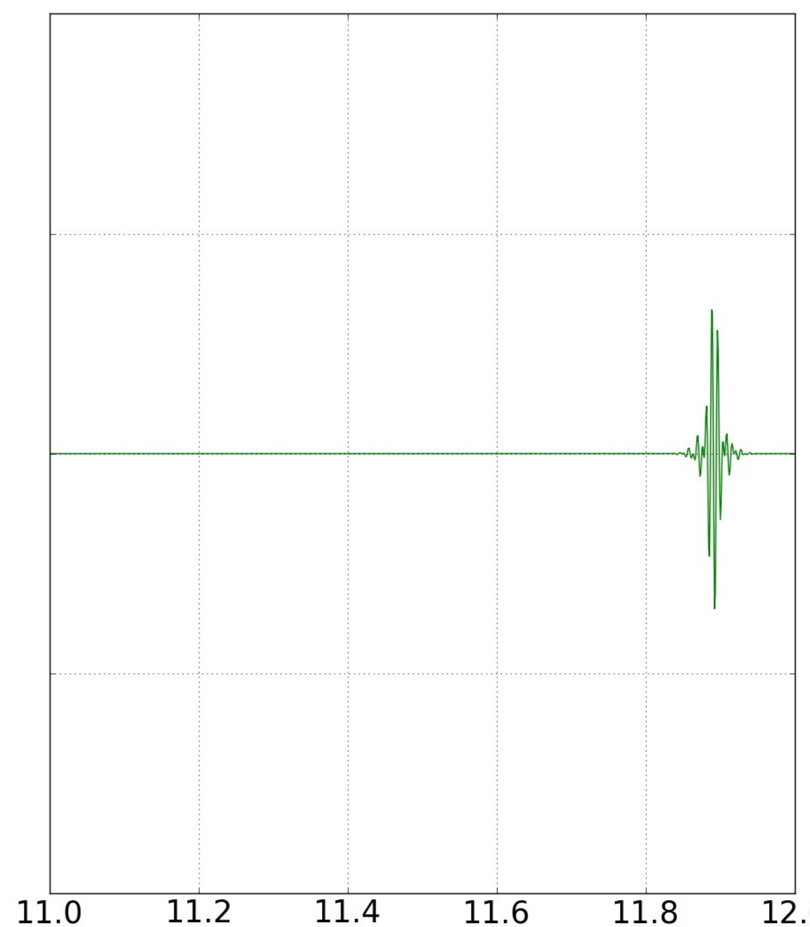


Reconstructed signal cumulated over iterations

Matching pursuit : 1st iteration

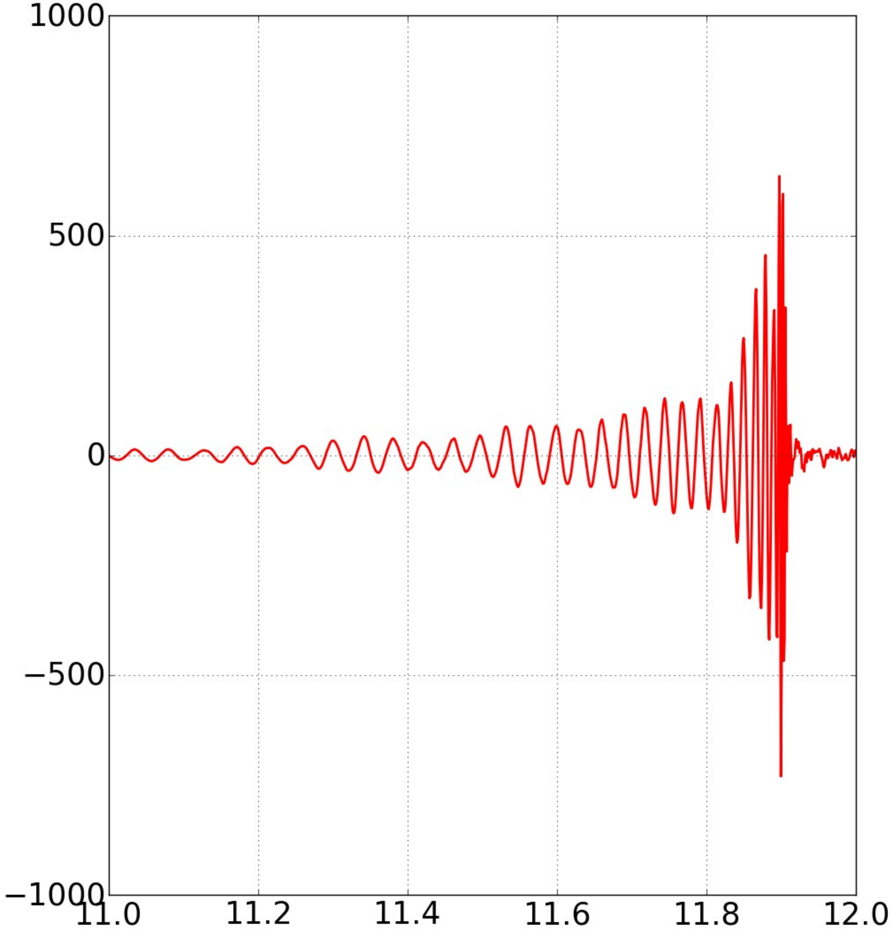


Residue

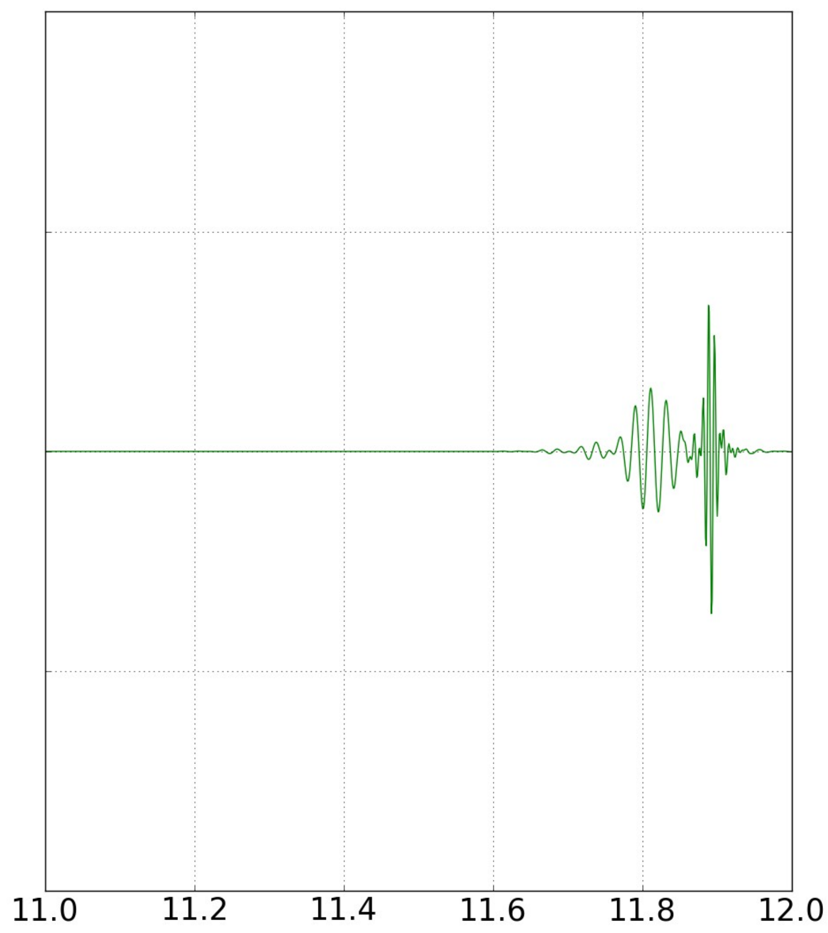


Reconstructed signal cumulated over iterations

Matching pursuit : 2^nd iteration

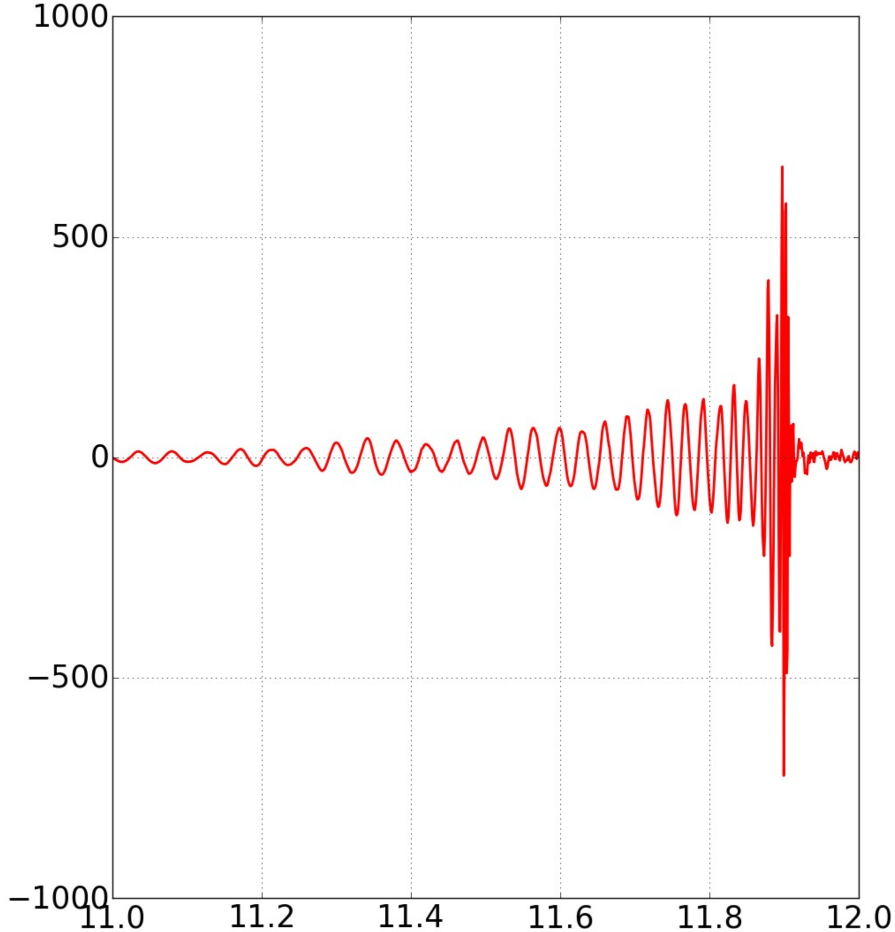


Residue

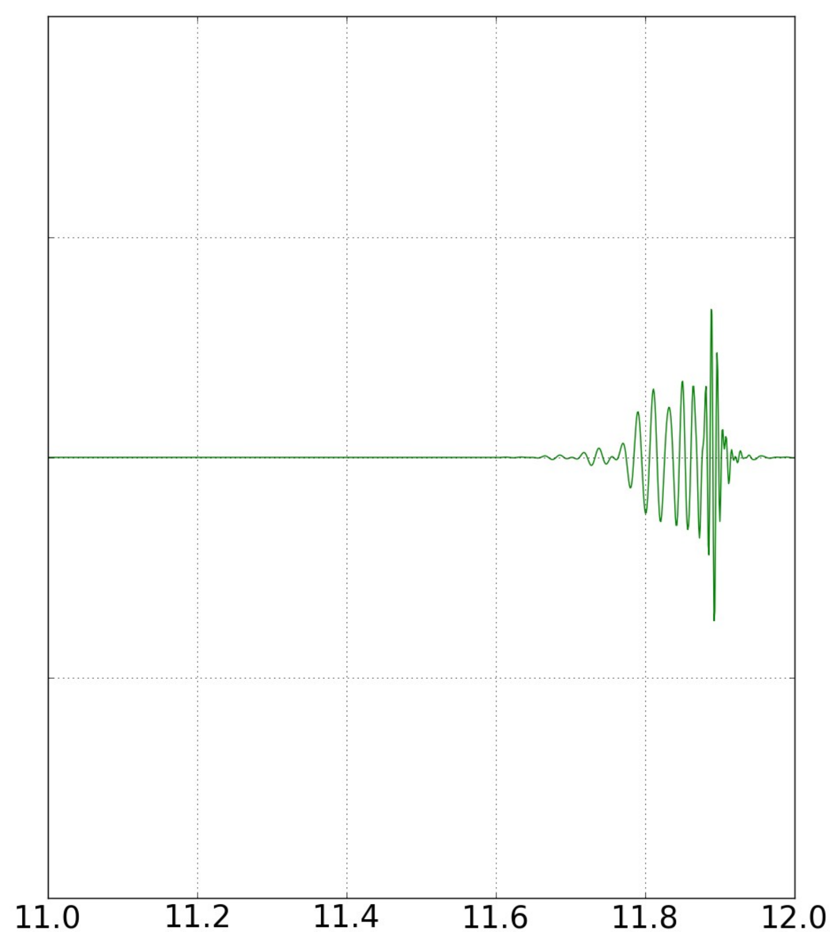


Reconstructed signal cumulated over iterations

Matching pursuit : 3rd iteration

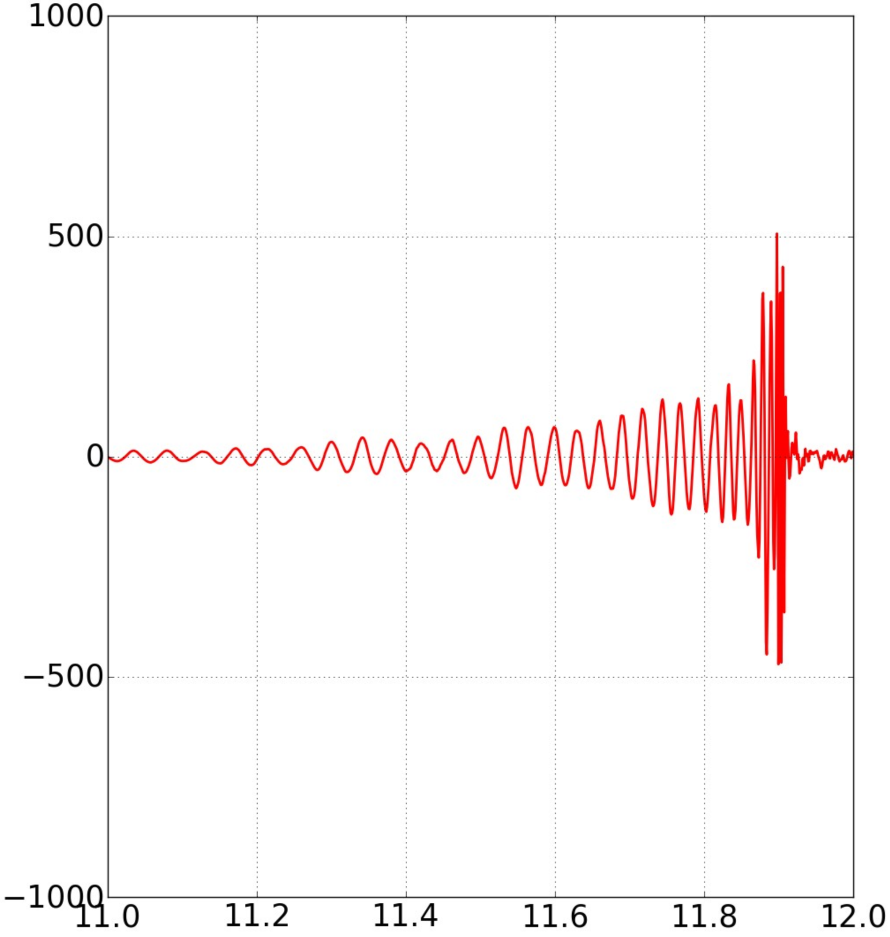


Residue

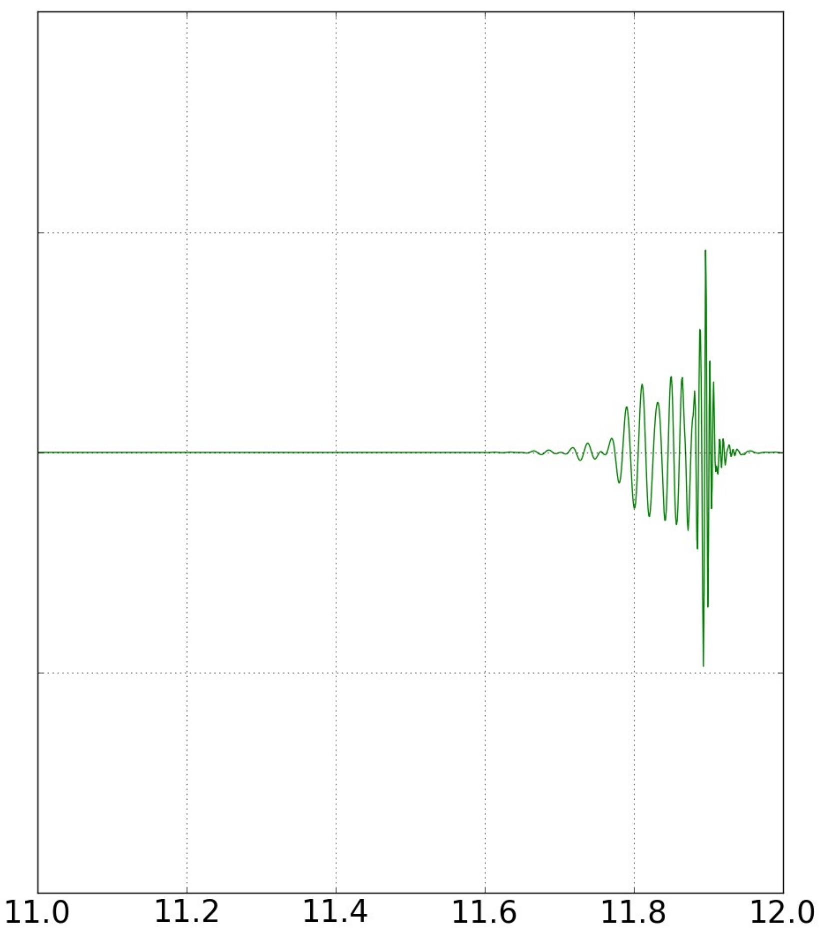


Reconstructed signal cumulated over iterations

Matching pursuit : 4th iteration

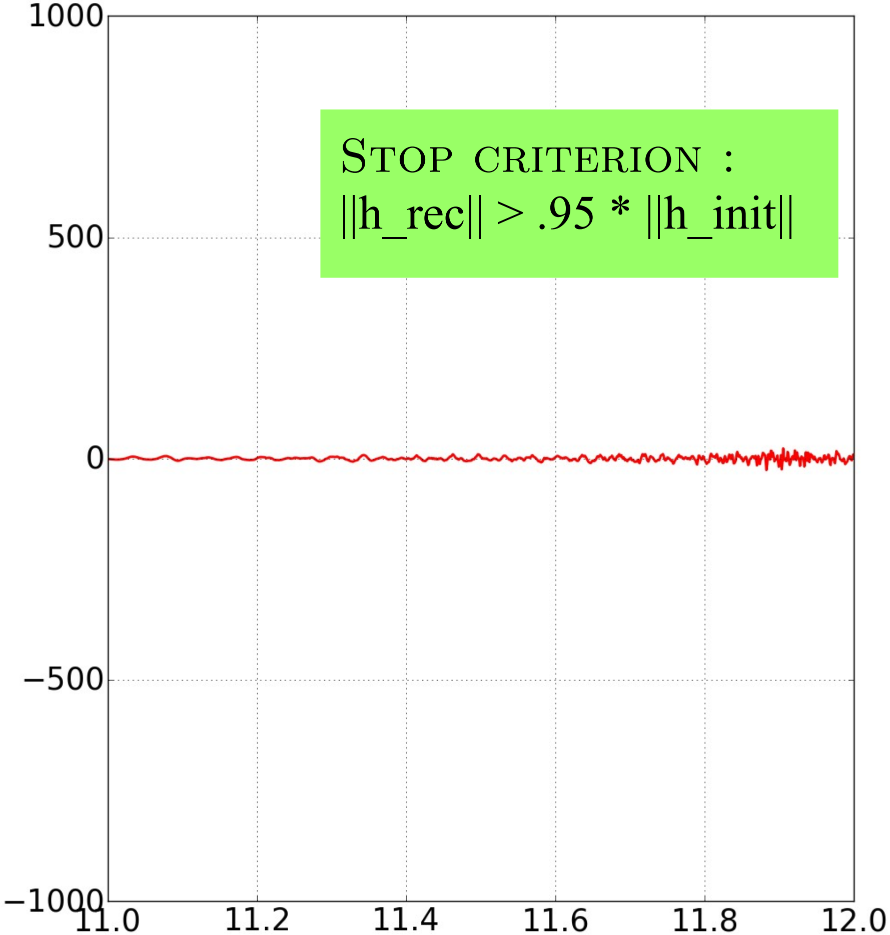


Residue

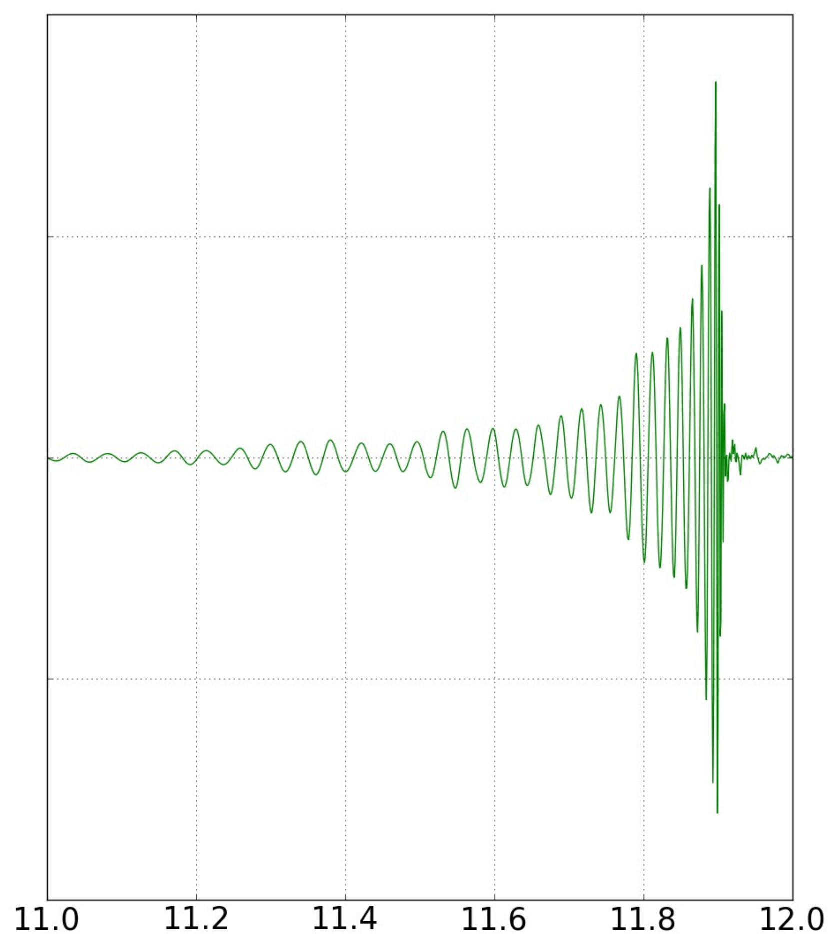


Reconstructed signal cumulated over iterations

Matching pursuit : final iteration

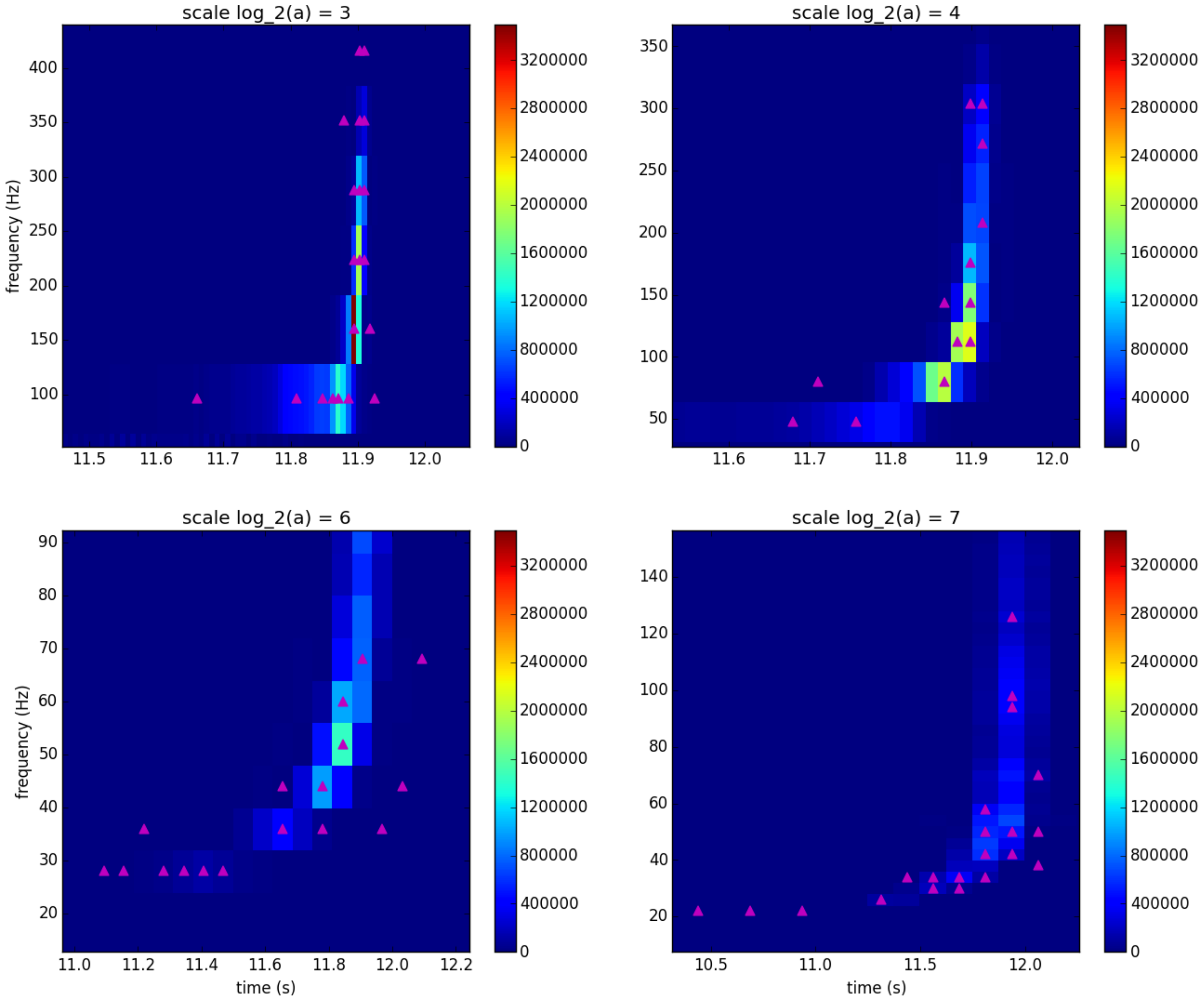


Residue



Reconstructed signal cumulated over iterations

Matching pursuit : final iteration



107 pixels have been collected