Fast Identification of Continuous Gravitational Wave signals

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The project

Gravitational waves all-sky searches for asymmetrically rotating neutron stars.

Constraining the parameters space with the fast stochastic background (SGWB) search pipeline, giving targets to the continuous waves (CW) directed narrowband search pipeline.

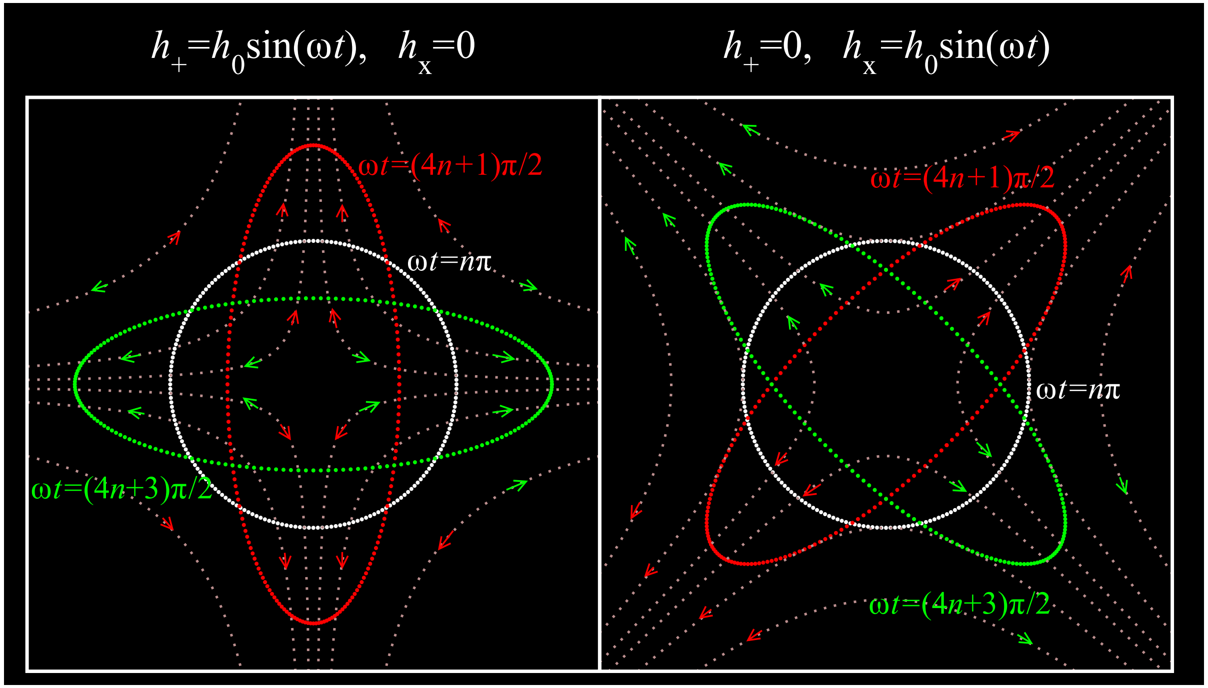
Contents

- Introduction on the gravitational waves
- The troubles of the all sky search
- The radiometer method
- The notable results of my studies

Gravitational waves

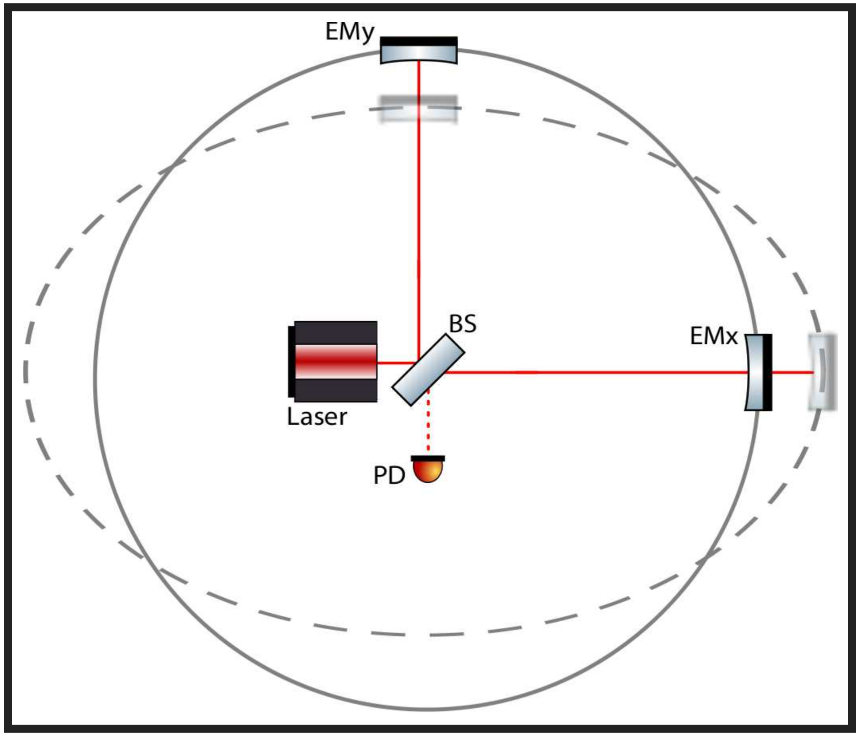
Perturbation $h_{\mu\nu}$ of the metric tensor. In small field and small perturbation approximations, we have in vacuum

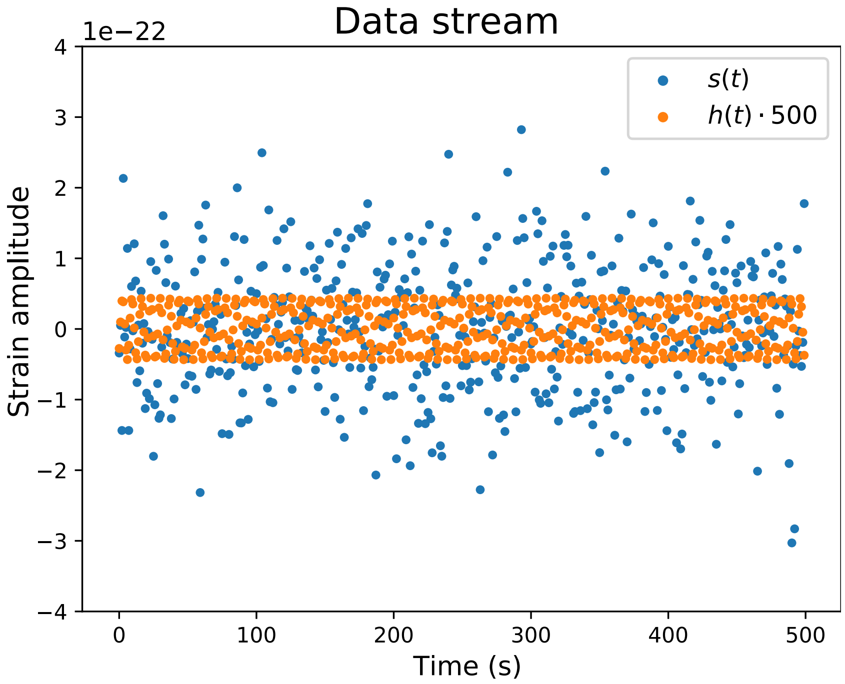
$$\left(\nabla^2 + \frac{\omega^2}{c^2}\right) h_{\mu\nu}(\omega, x^i) = 0$$



The data

Time series $s(t) = n(t) + h(t)$





The analysis

Matched filtering

$$S \propto \Re\left[\int_0^\infty \tilde{s}_1^*(f)\,\frac{\gamma(f)H(f)}{P_1(f)P_2(f)}\,\tilde{s}_2(f)\right]$$

Where the filter is determined by the detectors overlap factor (ORF) γ, their PSDs P_i and by the signal template function H, which depends on the source's parameters.

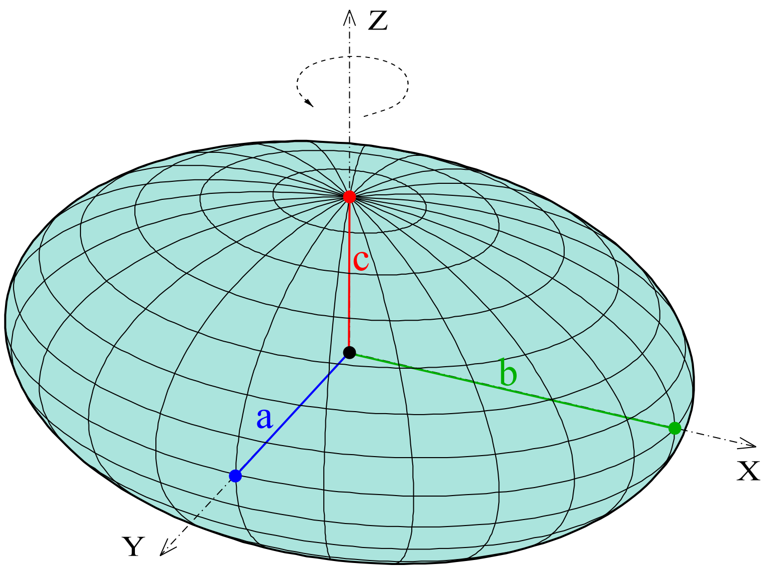
Continuous Waves

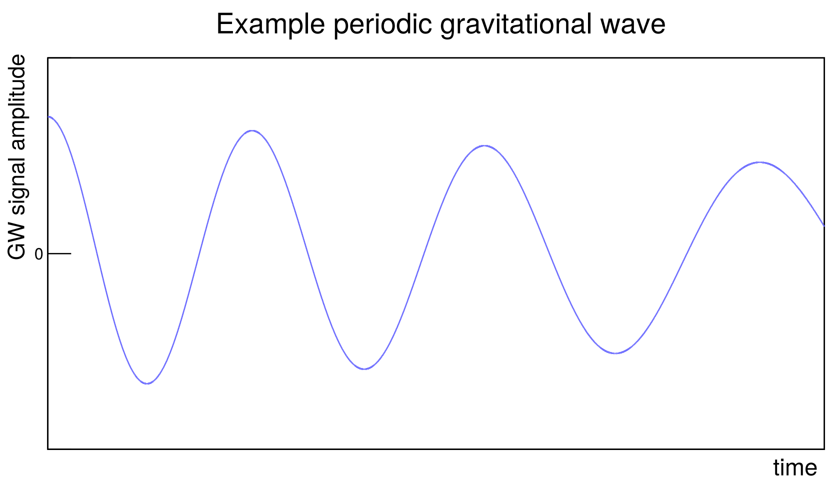
Generated by asymmetrically rotating neutron stars.

For isolated objects: signal amplitude $h_0 = \frac{4GI\epsilon}{c^4 r}\omega^2(t)$.

Tipically $\omega(t) = \omega_0 + k\dot{\omega}$.

(parameters space dimensions count: 2 $(\omega_0, \dot{\omega})$)





A general case

We have to take into account:

- Binary systems: signal's shape is doppler shifted by the orbital motion of the object

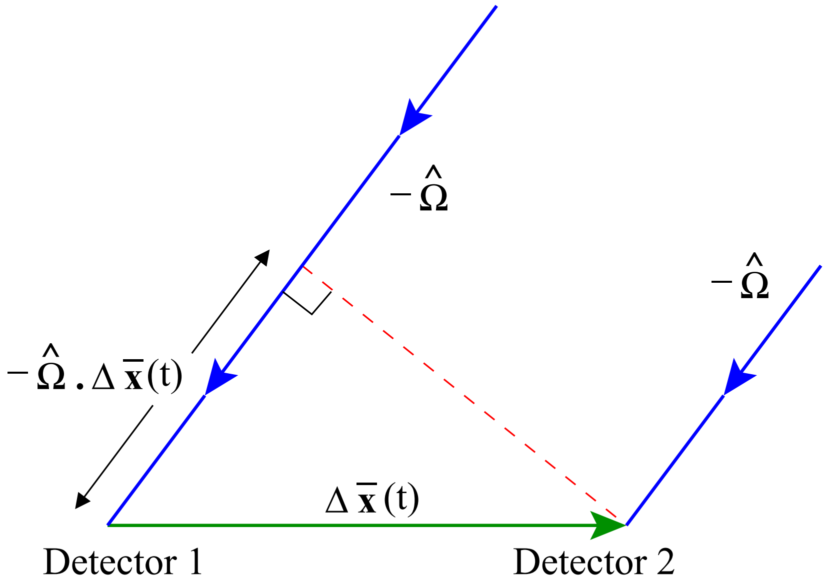
  (parameters space dimensions count: 5 ($\omega_0, \dot{\omega}, i, r_o, T_o$)

- Earth motion: doppler effect which depends on the source coordinates

  (parameters space dimensions count: +2 (α, δ))

A more general search: SGWB radiometer method

The phase difference between the two detectors in the baseline is used to cross-correlate the data



* Mitra, Sanjit, et al., Physical Review D 77.4 (2008): 042002.

The sky map

$$S_p = \frac{4}{t_s} \sum_{f,t} \tilde{\boldsymbol{s}}^*_{1,ft} \frac{H_f \gamma^*_{p,ft}}{P_{1,ft} P_{2,ft}} \tilde{\boldsymbol{s}}_{2,ft}$$

$$= \frac{4}{t_s} \sum_f H_f \sum_t \tilde{\boldsymbol{s}}^*_{1,ft} \frac{\gamma^*_{p,ft}}{P_{1,ft} P_{2,ft}} \tilde{\boldsymbol{s}}_{2,ft}$$

For any point p a semi-coherent search that cross-correlates segments of length t_s, and then integrates over them along the whole run

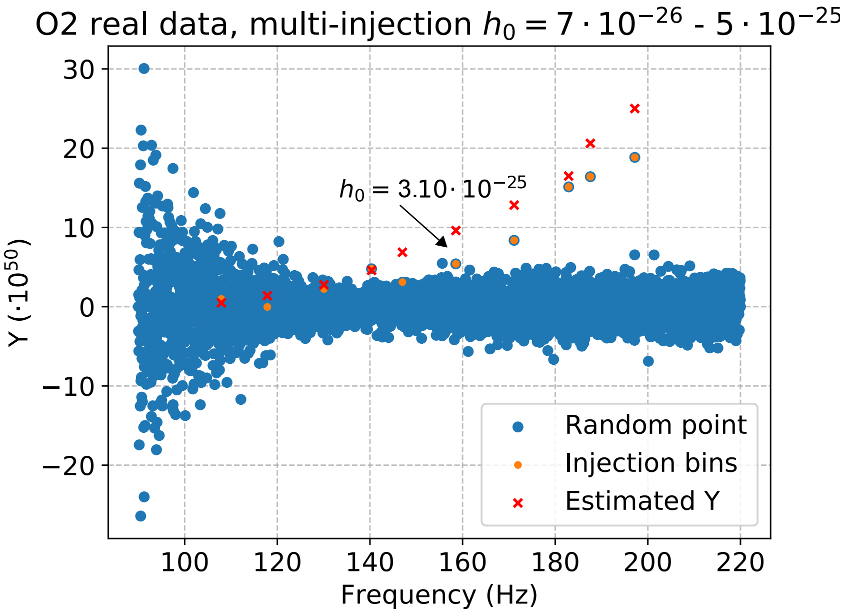
Tests

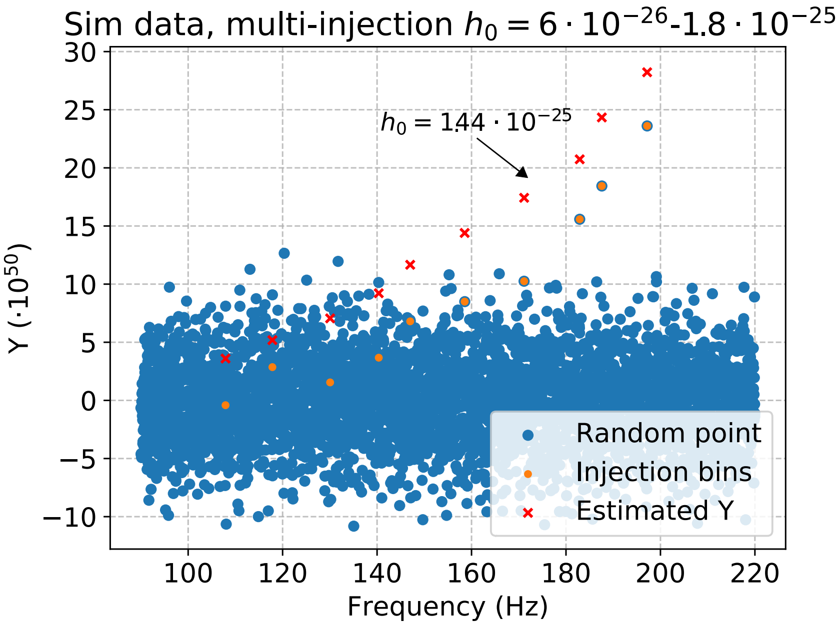
- Software injections on real data from the LIGO Hanford and Livingston detectors (11/30/2016 - 08/25/2017 O2 run)
- Tests on simulated noise with flat design noise levels ($\sqrt{S_h} = 4 \times 10^{-24} Hz^{-1/2}$)

In both cases ~3 months of contiguous data,
data sampled at 256 Hz,
analyzed between 100 and 200 Hz,
$\delta f = 1/32\, Hz, t_s = 192\, s$

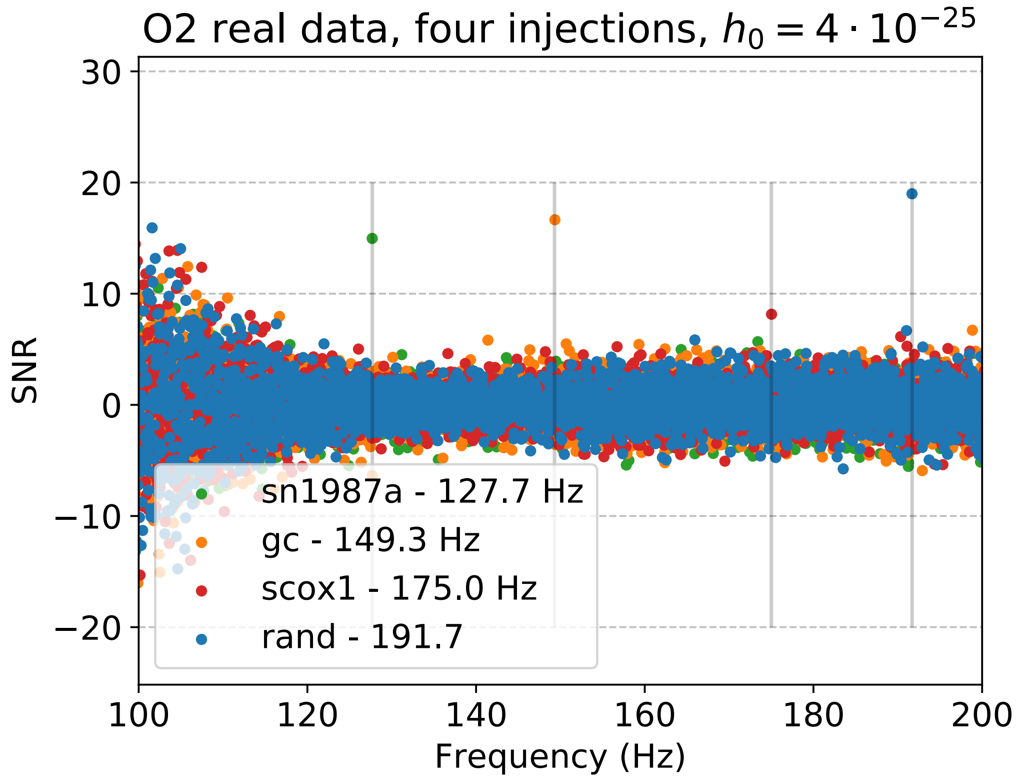
Detection statistics

$$Y_p = \sum_t \tilde{s}^*_{1,ft} \frac{\gamma^*_{p,ft}}{P_{1,ft} P_{2,ft}} \tilde{s}_{2,ft}$$



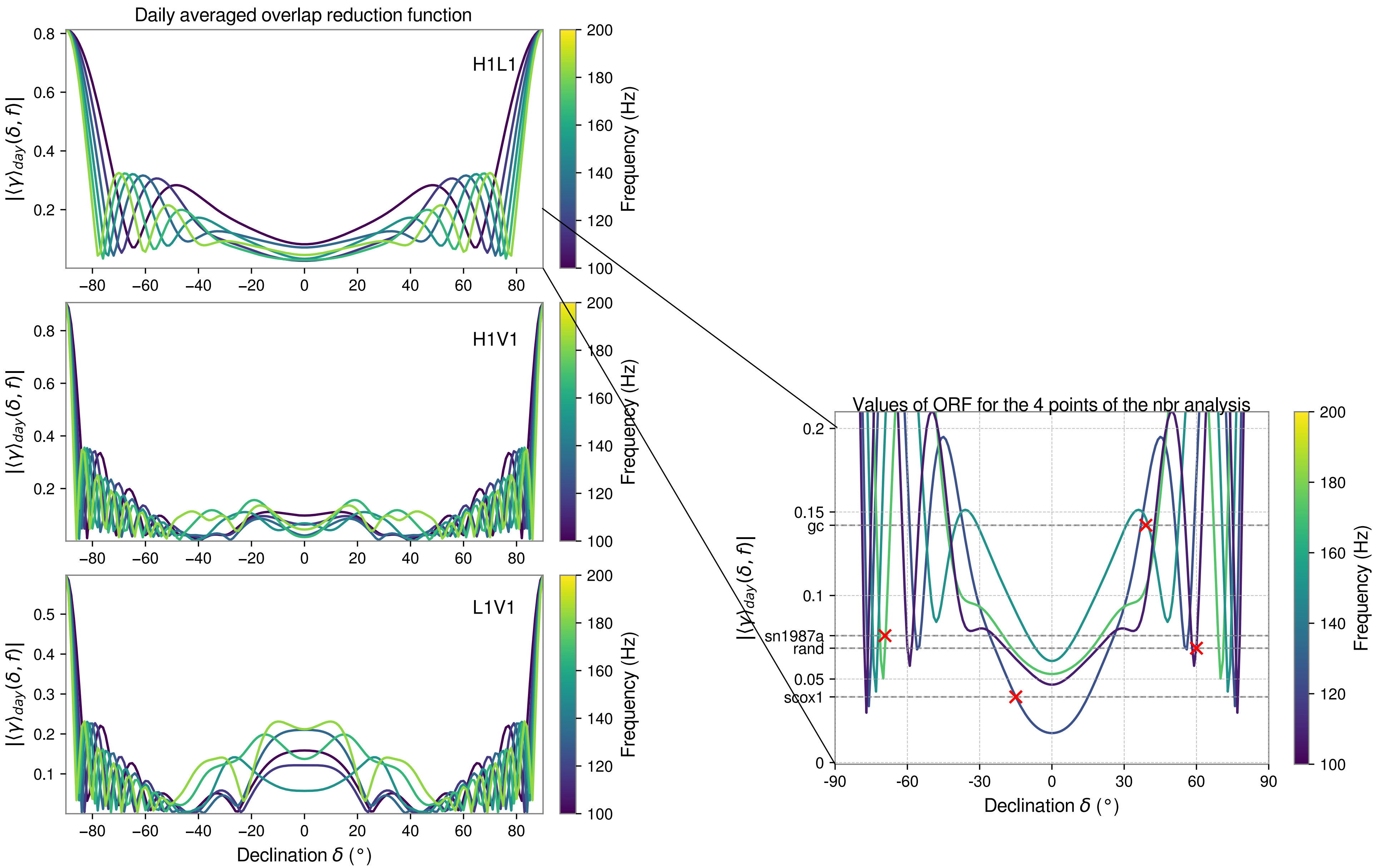


The stochastic narrowband search case



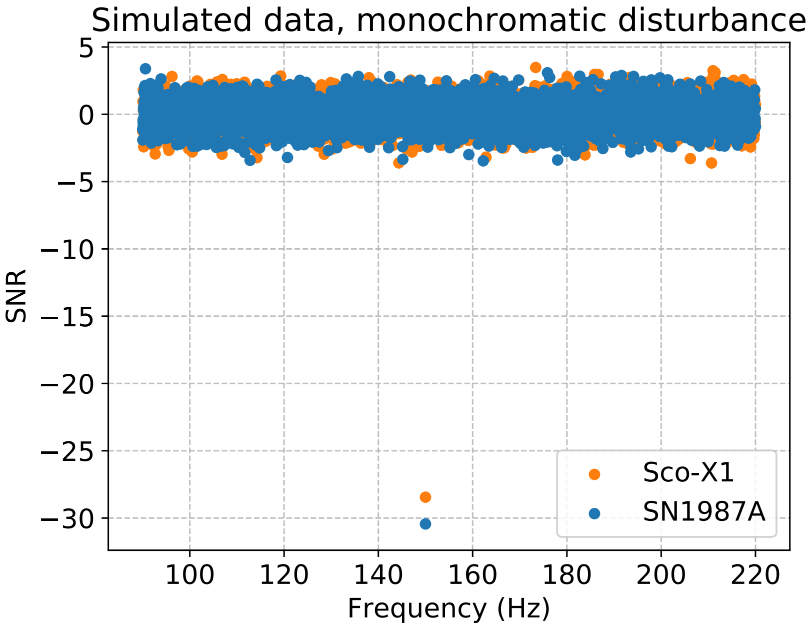
The signal are loud and they are retrieved correctly, probably `scox1` is lower because the overlap reduction function

Non trivial behavior of overlapping detectors



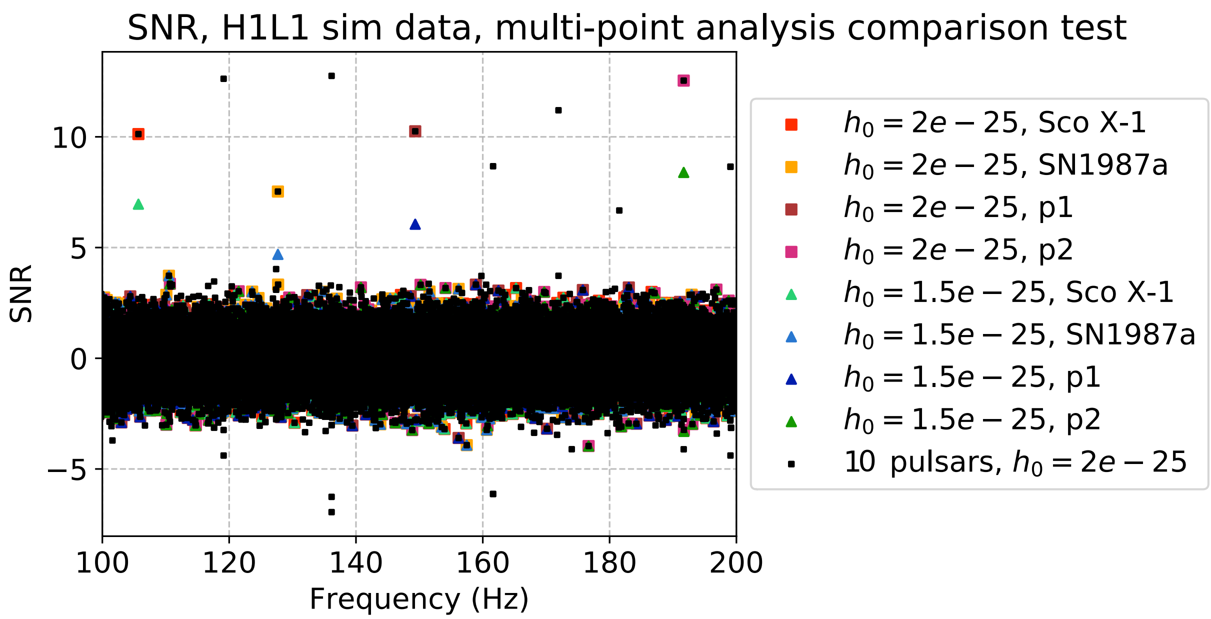
Thanks to the higher control with simulated noise data, several other tests have been done, for example:

- Monochromatic disturbance



A correlated disturbance is shown as "negative SNR"

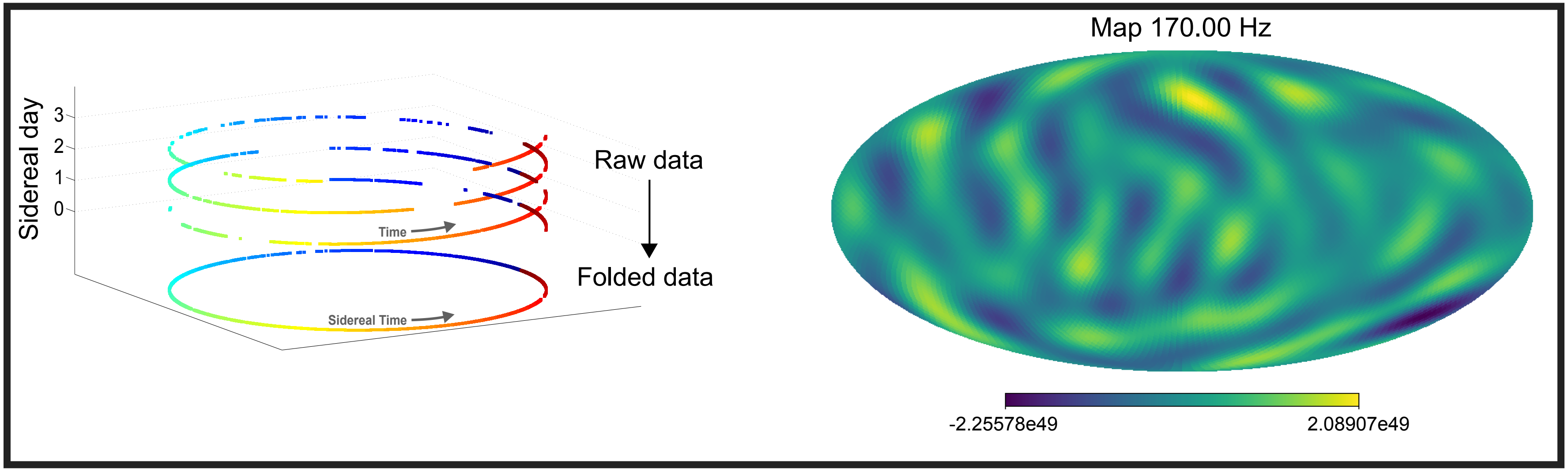
- Reproducibility with different number of signals



- Colored: 4 pulsars tests at $h_0 = 1.5\text{-}2 \times 10^{-25}$
- Black: 10 pulsars test at $h_0 = 2 \times 10^{-25}$
- SNR doesn't depend on the number of signals

New tools

- Use of the folded data
- A new version of the pipeline that builds the full narrowband map at once for each frequency bin

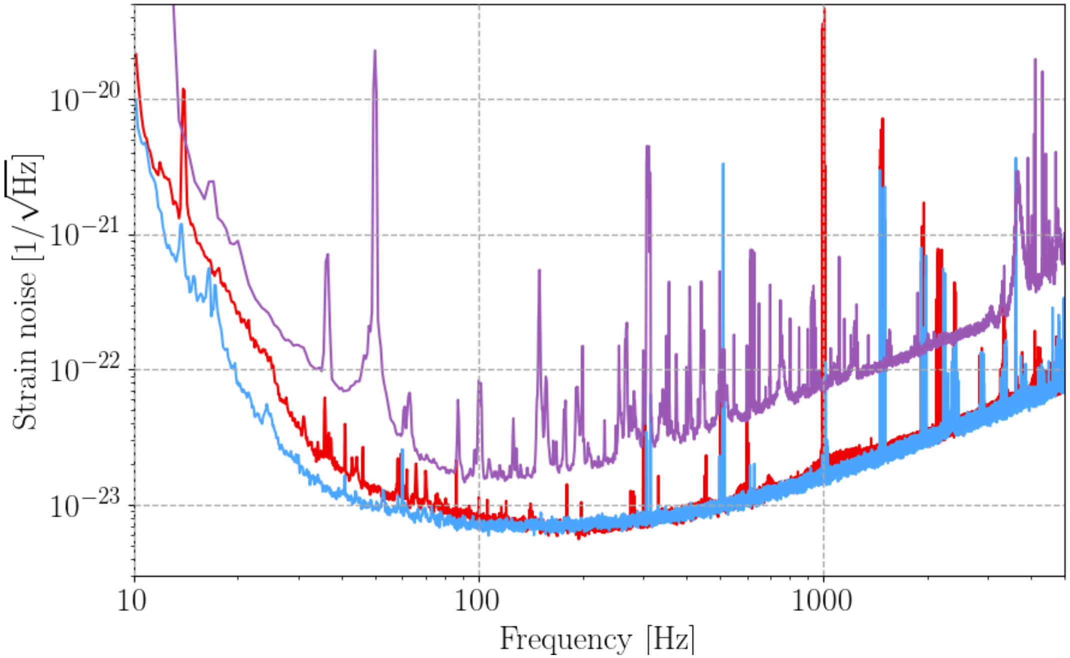


Conclusions

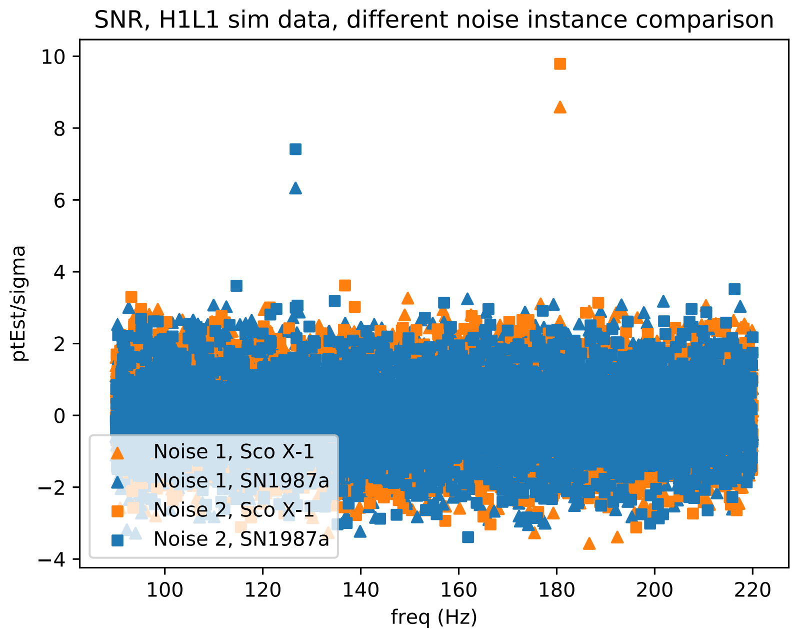
- Further tests to be done (e.g. role of the ORF)
- The pipeline is almost fully characterized for the next step
- Study how to apply the pipeline to a CW real case search

Thank you!

- Sensitivity curves



- Different noise instances



• Different baselines