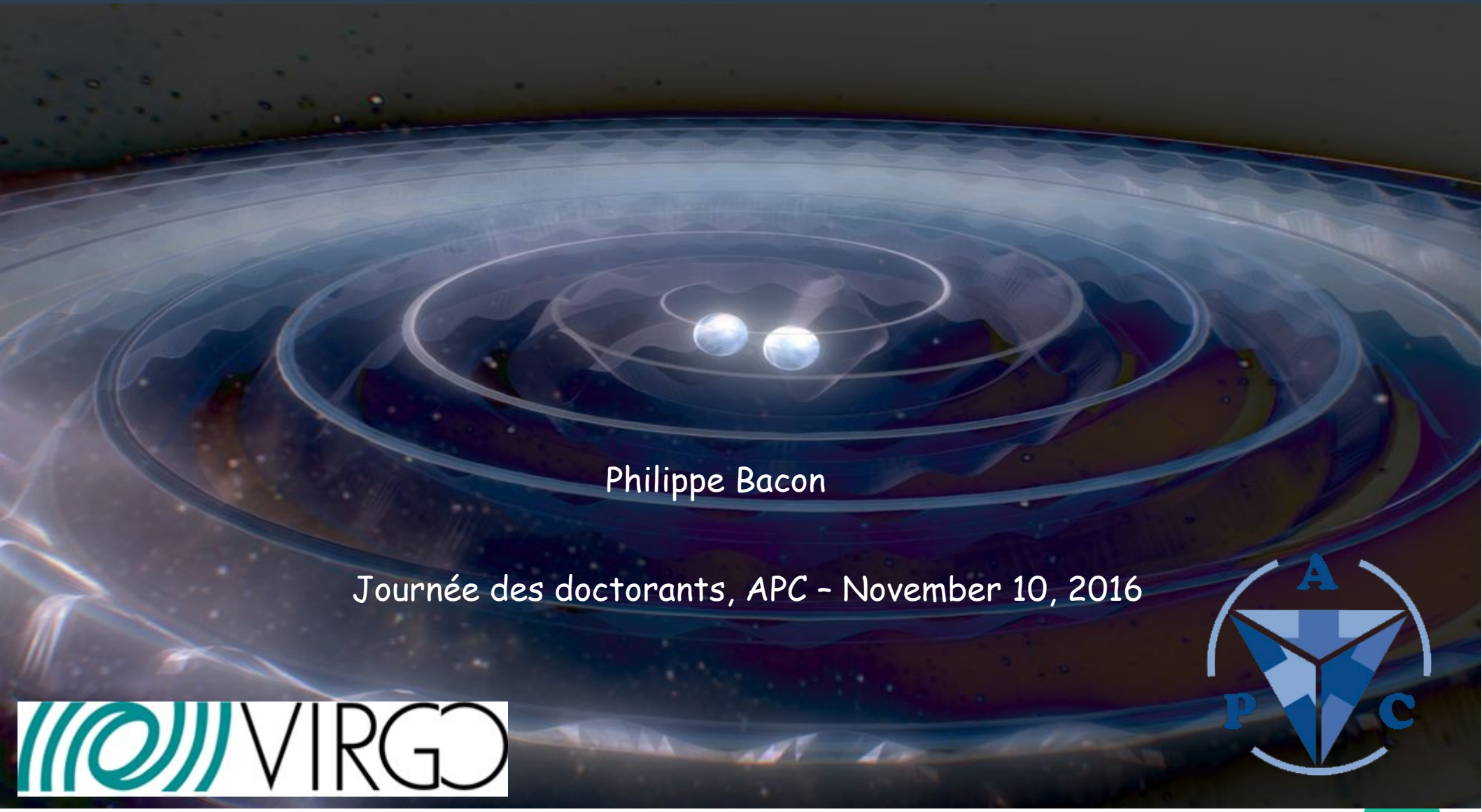
Wavelet-based search for gravitational wave detection



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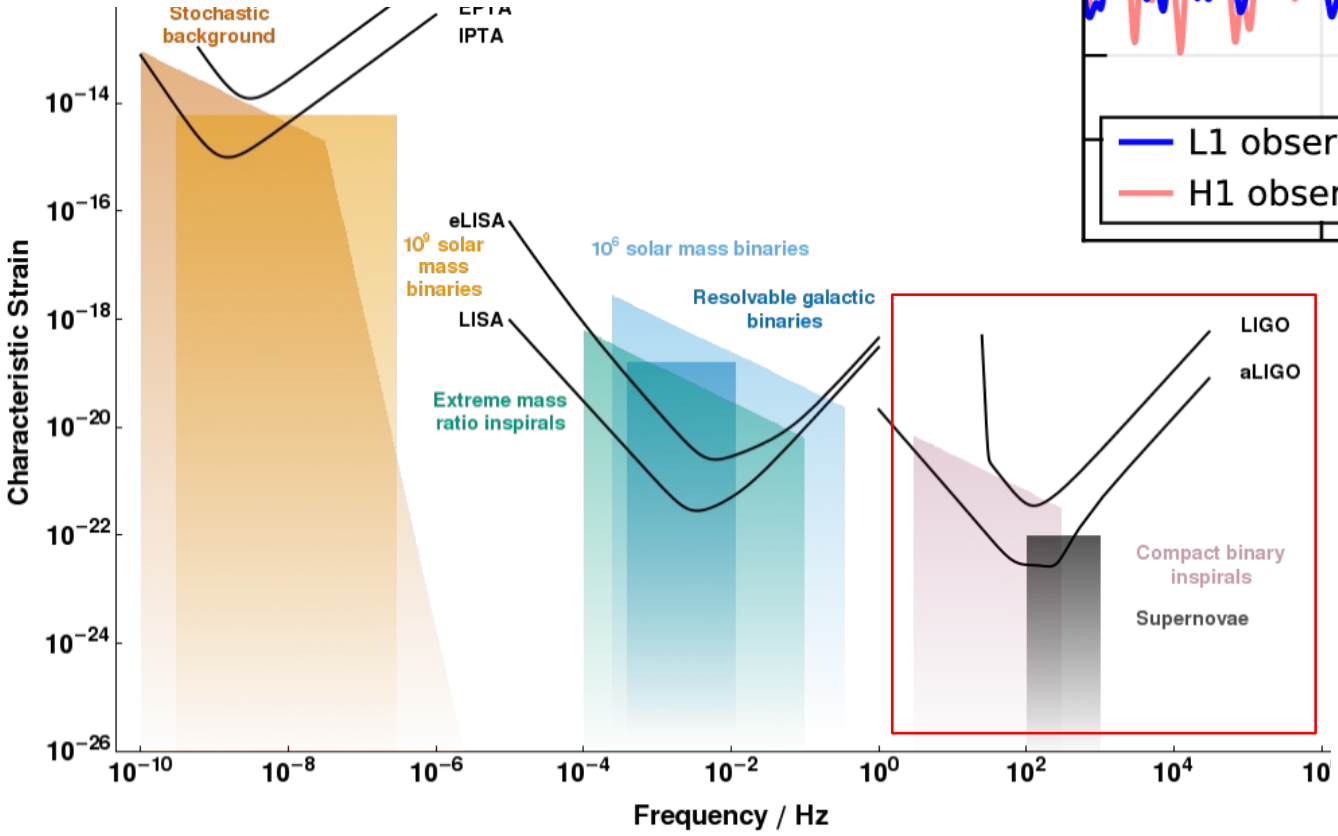
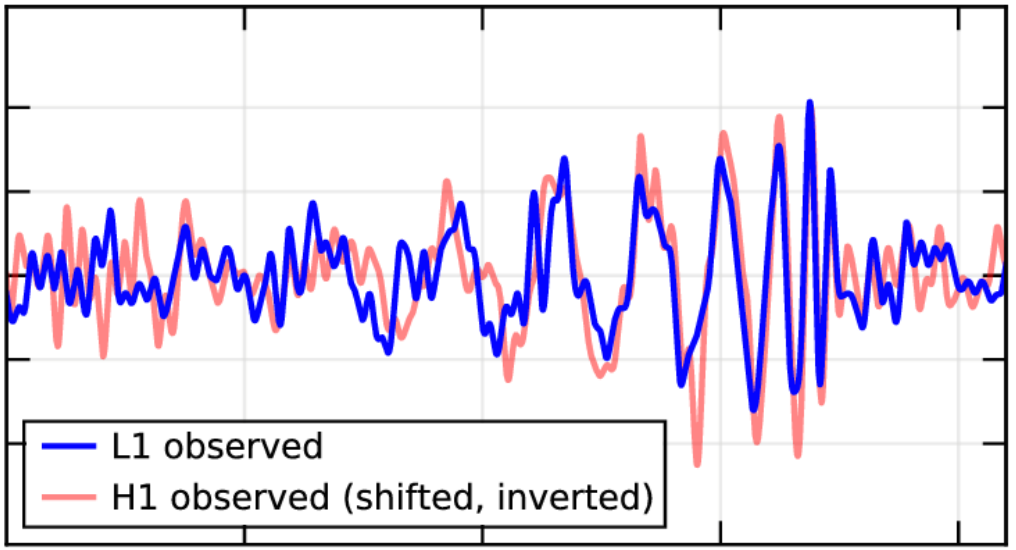
Journée des doctorants, APC – November 10, 2016

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 !

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

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 binary black-hole merger 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

Wavegraph : a big picture

Wavegraph :

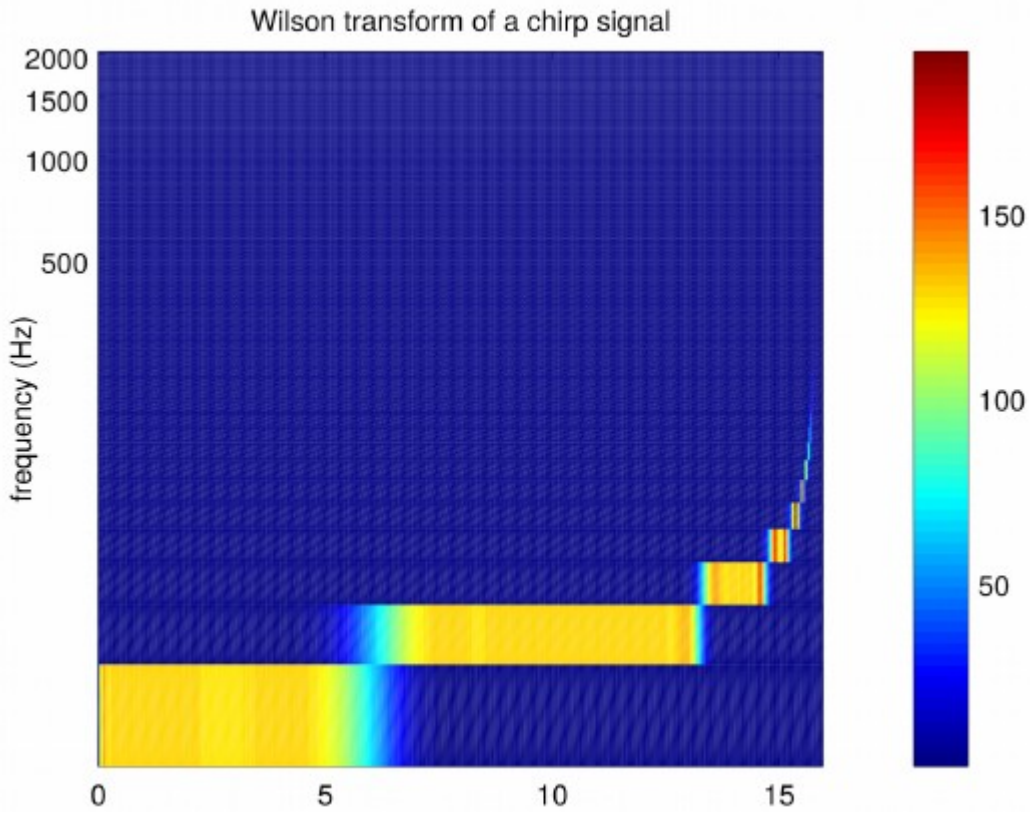
- Is a clustering scheme dedicated to an existing pipeline which is looking for some excess power in an interferometer network : **coherentWaveBurst (cWB)**
- Its goal is to incorporate astrophysical information in coherent GW burst searches at clustering step.
- Improves performances of coherent searches for "chirp"-like signals.

Wavegraph : basics

Basic idea :

- Chirp signals possess a 1D time-frequency structure.
- **Wavegraph** is a clustering scheme that targets clusters of this shape
- As cWB, it makes use of a wavelet basis to decompose chirp over many t-f resolutions.
- We *a priori* select the wavelets that will best fit the chirp (WDM transform)

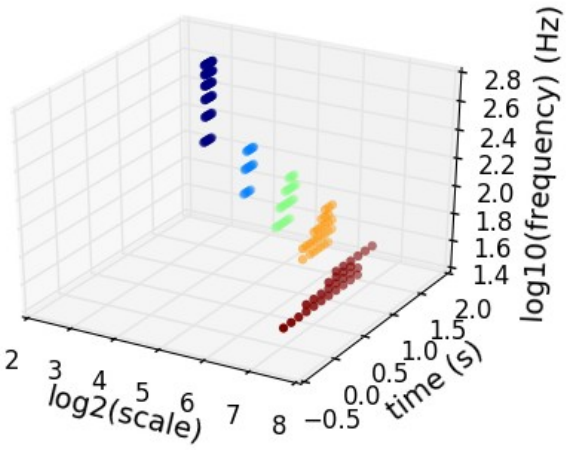
  → Form **chain of wavelets**



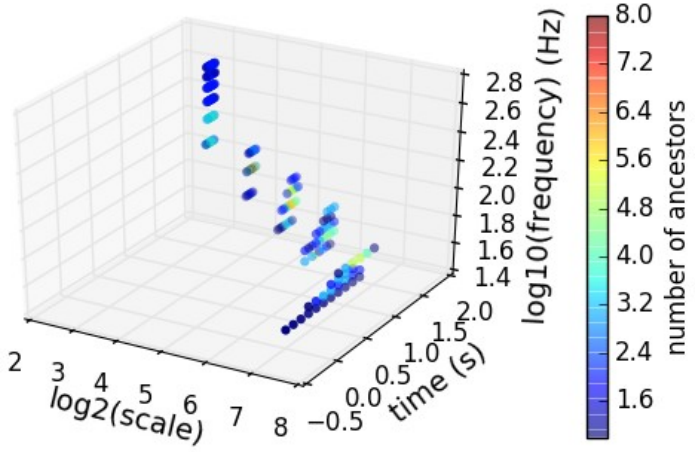
Wavegraph : application to CBCs

Producing chains of wavelets over a range of chirps covering the parameter space.
Merging them into a graph.

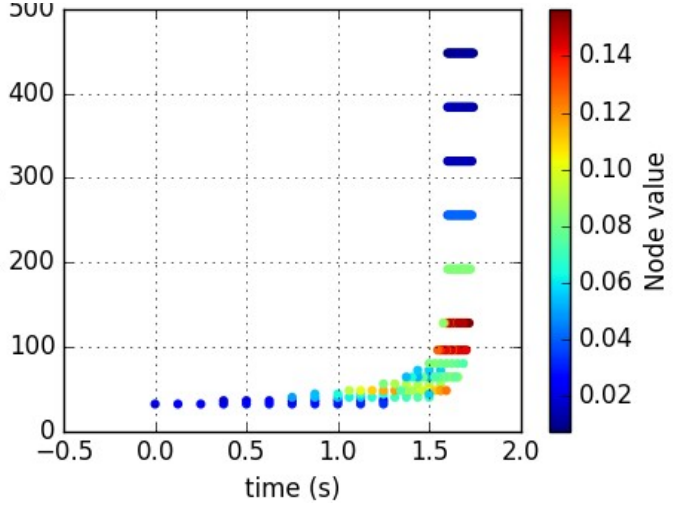
Here is a 225-node graph – BBH Total mass = 20 – 40 Msun.



Time, frequency, scale space



Num ancestors

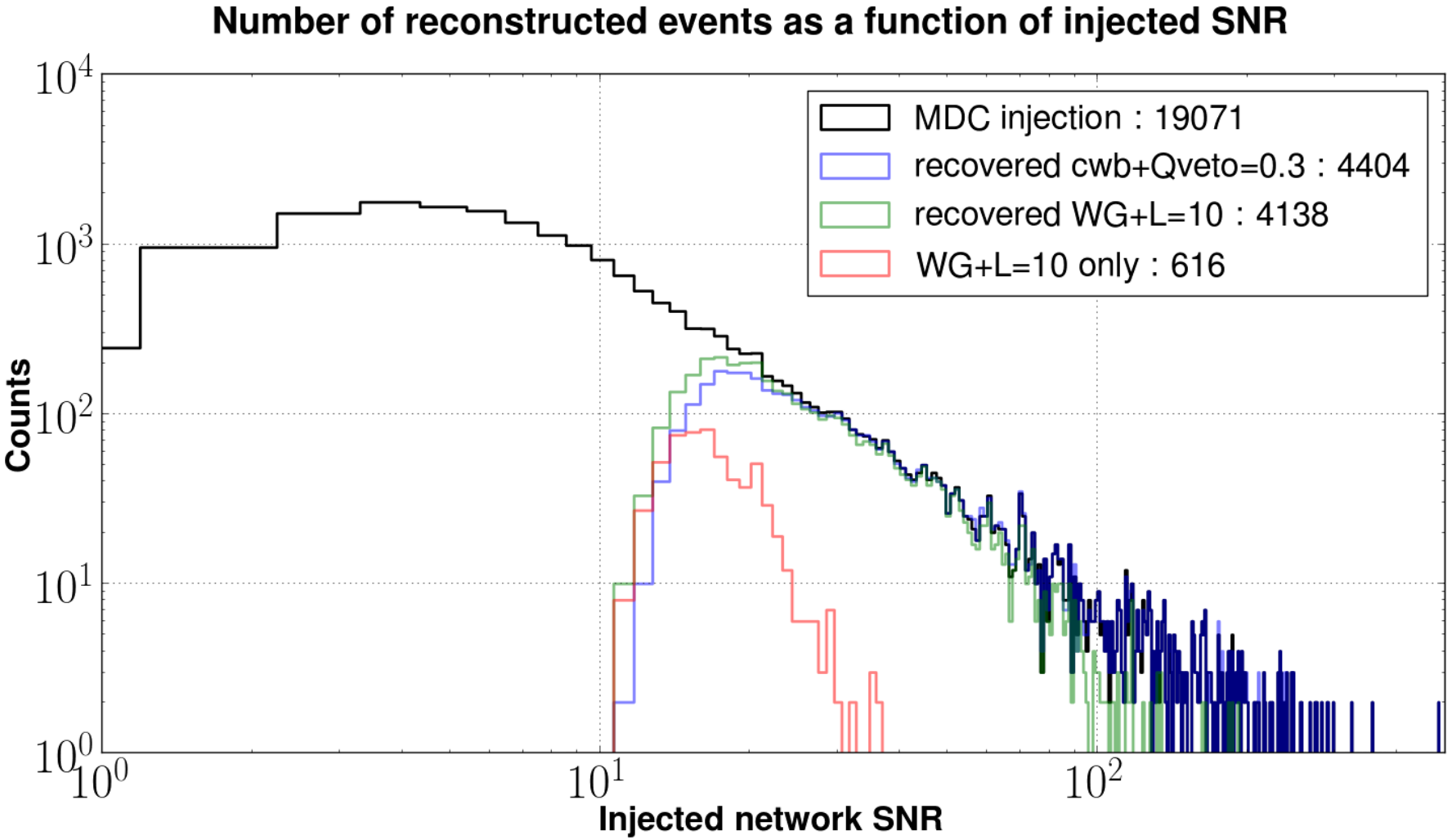


Node values

Graph is filled with observed whitened data.

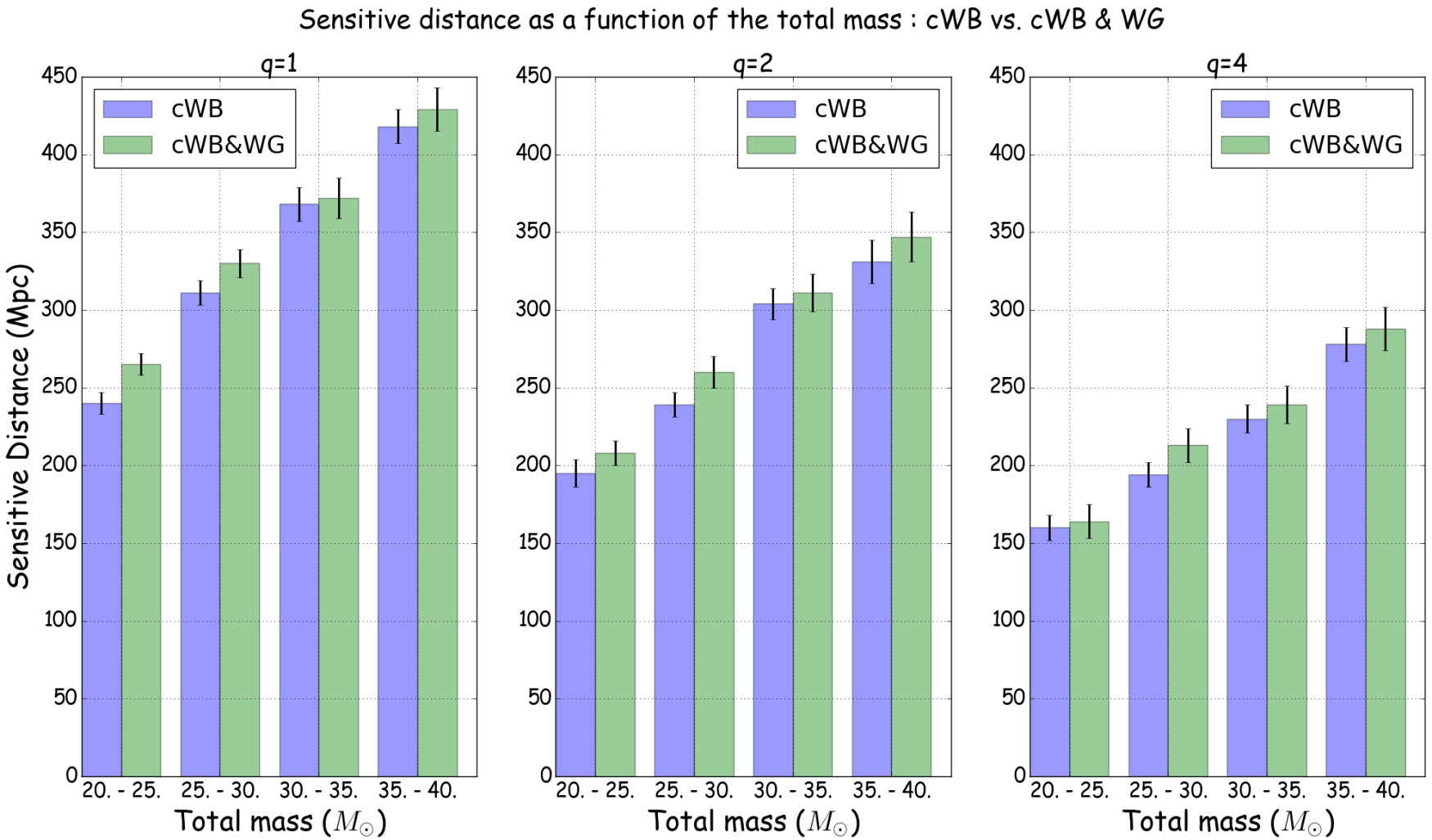
Search for the optimal path in the wavelet graph by maximizing the SNR over all the paths in the graph.

WG in action : reconstructed events vs. injected SNR.



- Recovering more events in the low-iSNR range (around 10 %)
- Noticeable complementarity : cWB+WG is recovering 616 additional events unseen by cWB alone (cWB only : 883).

WG in action : sensitive distance reach

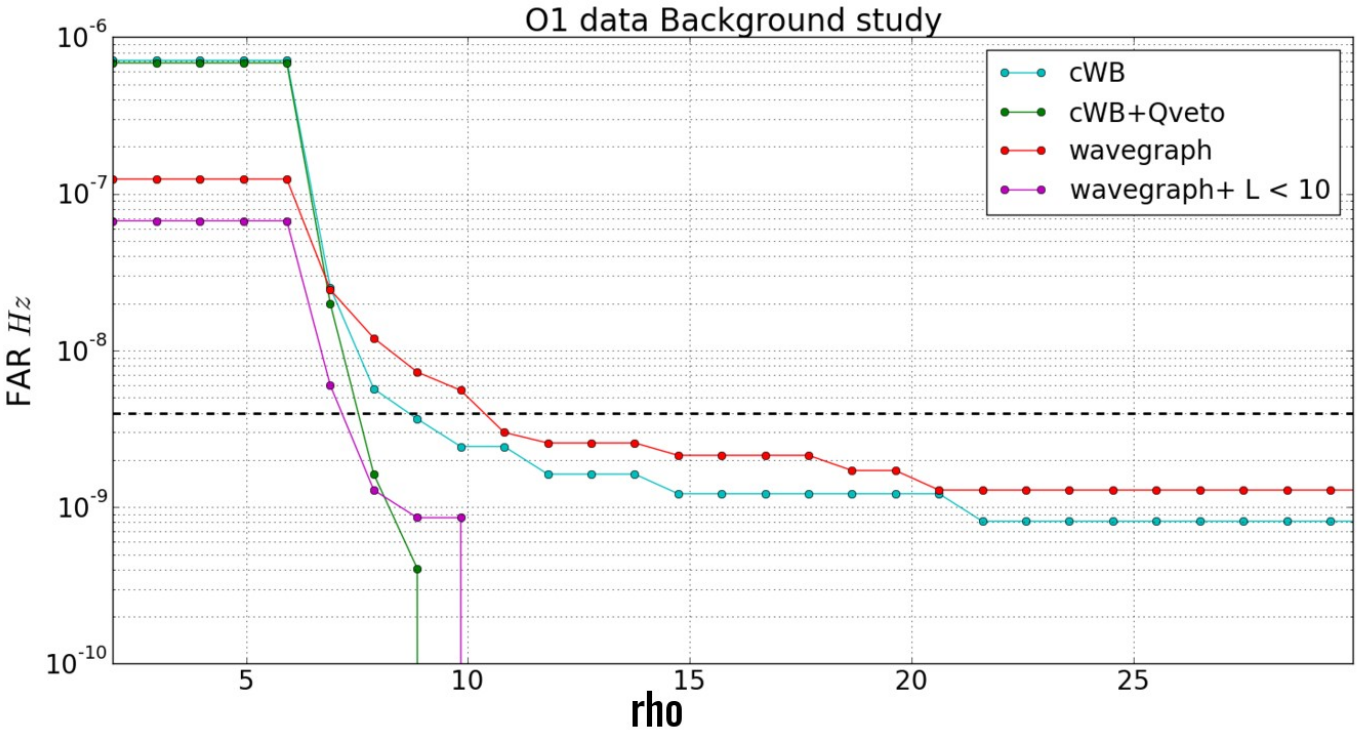


On average over mass bins, we are improving the observed volume by 15 % at fixed mass ratio q.

Consistency test & background study.

- A model-based consistency test in tandem with the detection statistic (here rho) can help to reject glitches as belonging to the noise.

- Similar to a chi-square test to compare observed data with a model.

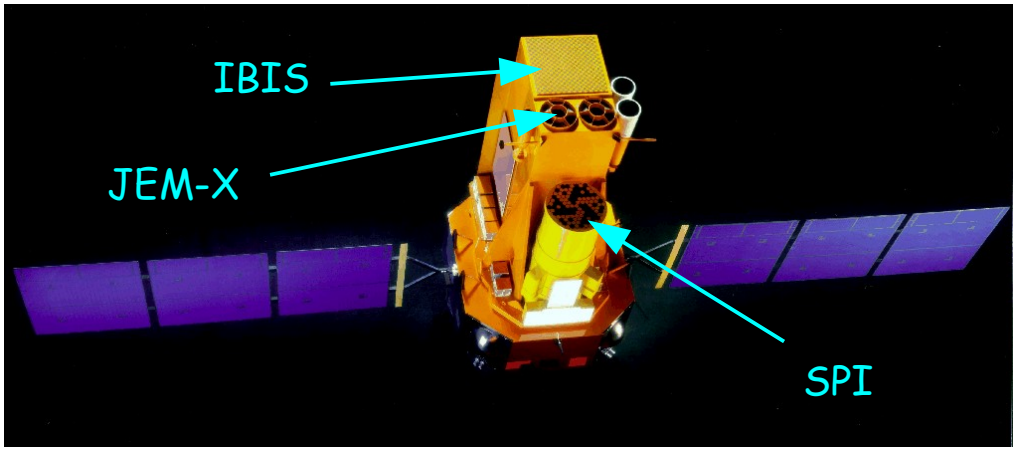


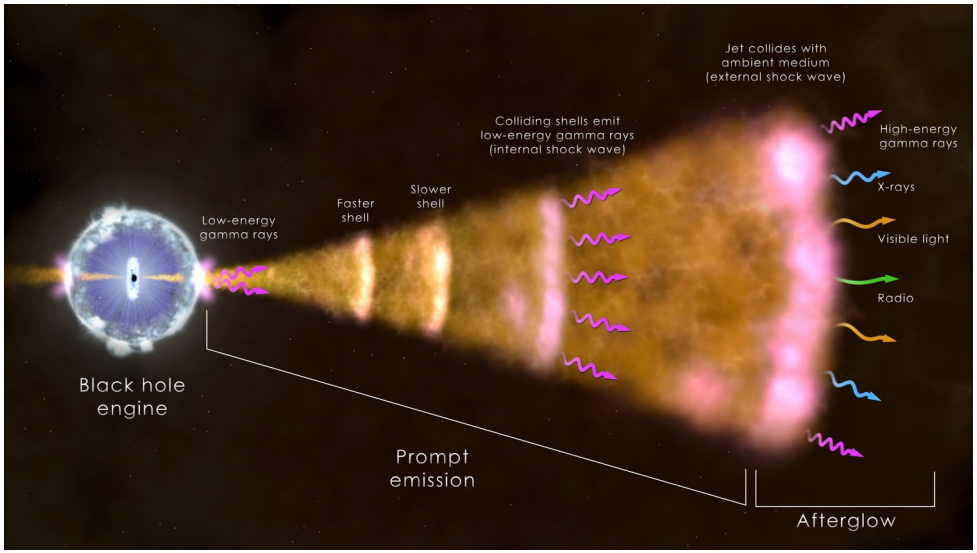
Glitch = Undesired transient noise of (un-)known origin in data stream.

Significant tail reduction with L < 10 is comparable to the one obtained with Qveto

Gamma-ray follow-up of GW triggers. (1/2)

Investigate high-energy follow-up of GW triggers (LIGO+Virgo) associated to short gamma-ray bursts (sGRB) with the instruments on board INTEGRAL.



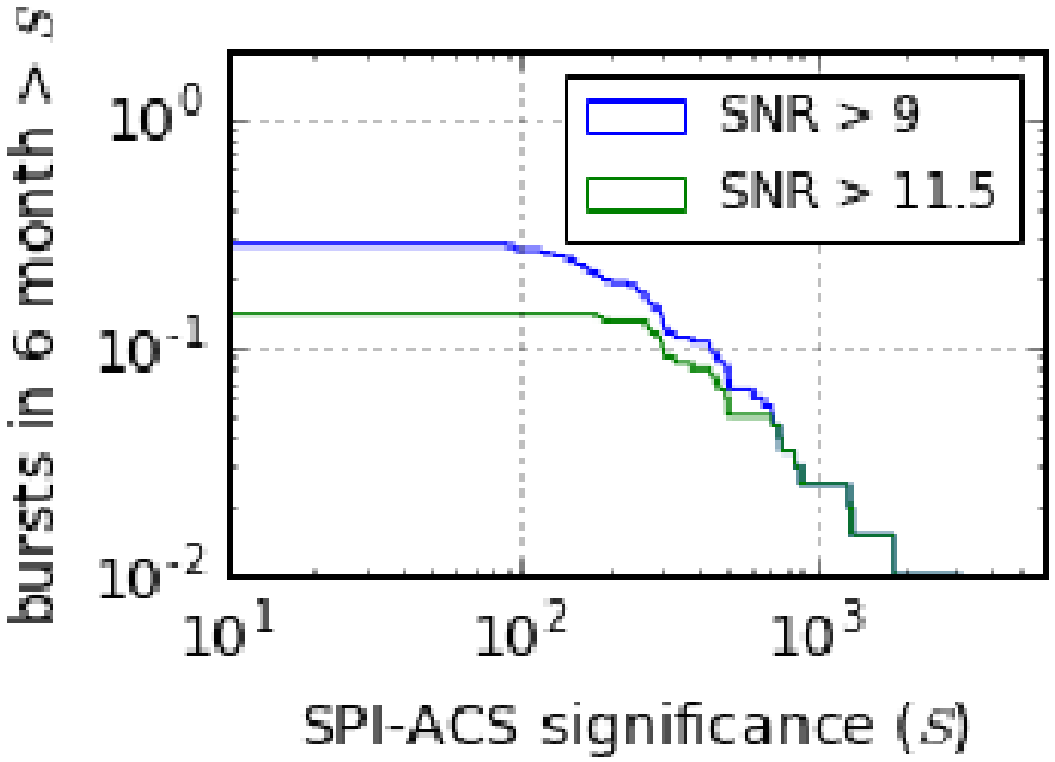


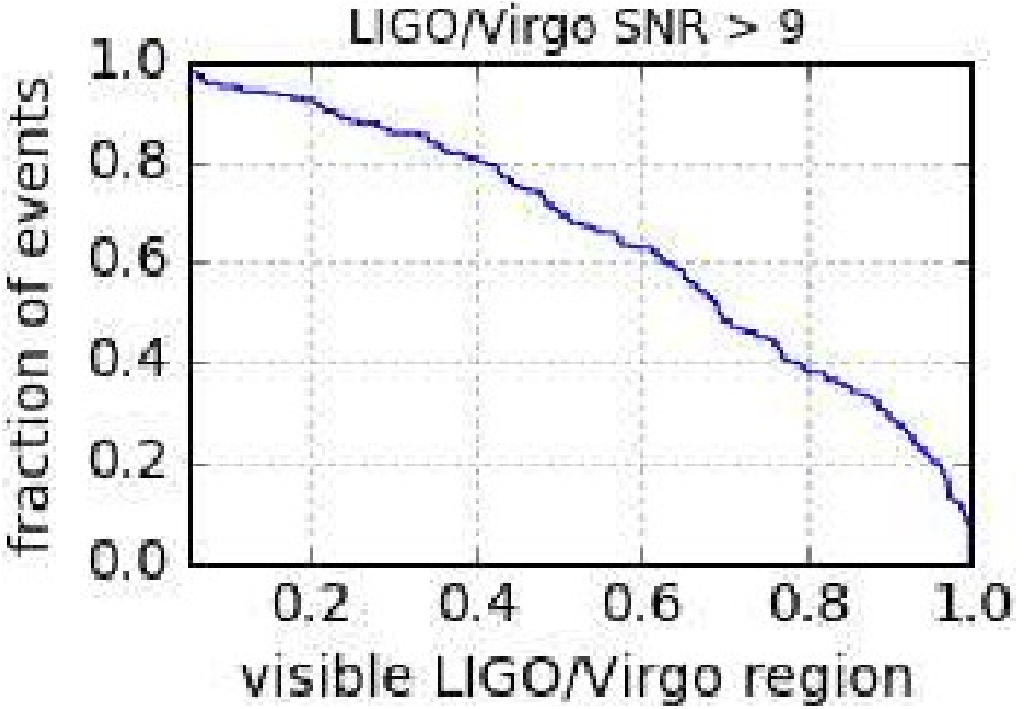
Address the following questions :

- What should be the individual significance of a GW events and a EM event to claim a confident joint detection (> 5σ) ?
- Within some assumptions on sGRB models, what is the expected BNS detection rate commonly detected by LIGO/Virgo and INTEGRAL ?

Gamma-ray follow-up of GW triggers. (2/2)

End-to-end simulation of both GW and EM events for a population of BNS mergers.





Prompt emission : detected by INTEGRAL with a 50σ significance AT LEAST.

→ Detection rate : 0.1 to 0.5 in 6 months of O2 for these SNR. values.

Afterglow emission : in 40% of cases, 80% of the source is observed.

→ Detection rate : 0.1 events in 6 months.

Conclusion

- **Wavegraph** is a new clustering scheme dedicated to cWB whose aim is to include astrophysical information in burst searches.
- For BH binaries, Wavegraph shows complementarity with cWB in the low-mass range + better sensitivity (until 48% improvement in detection rate)
- The introduction of a consistency test significantly reduce the background tail.
- Initiated an study on the joint visibility/detectability of high-energy (γ, X) and GW events with INTEGRAL.
- Reveals we should expect ~ 0.1 BNS mergers in a 6-months run under some model assumptions…