Search for gravitational waves produced by cosmic strings using data from the first advanced LIGO-Virgo observing run

Imène Belahcene
Director : Florent Robinet and Patrice Hello

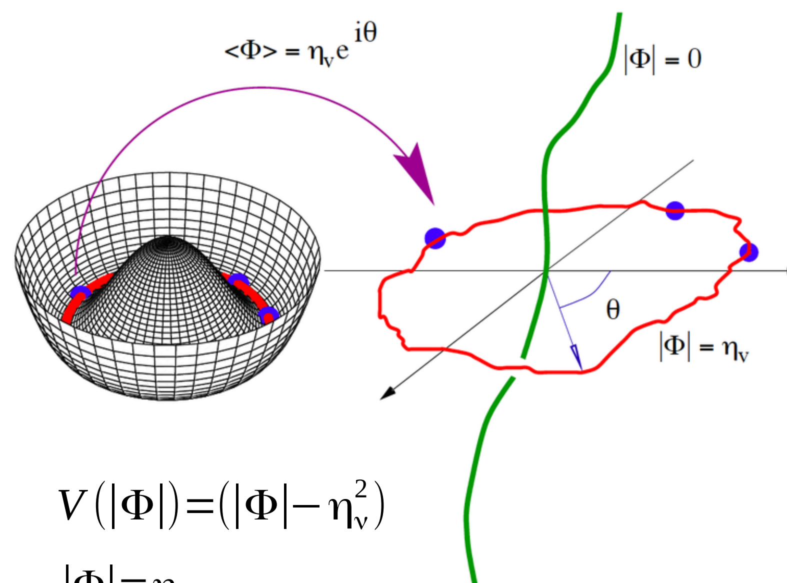
Cosmic String in a nutshell

- In the early hot expanding universe, spontaneous symmetry breaking may have left behind topological defects.
- **Cosmic strings are 1-D defects** (Kibble)
- Motivate the existence of string solutions :

  - If a field theory has symmetry breaking patterns, the vacuum state may not be unique.
- example :

  Φ : complex scalar field.

  By contracting the circle we reach a point where we can not go further without leaving the manifold. A small region where Θ is not defined. This region line-up and form a line-like defect.

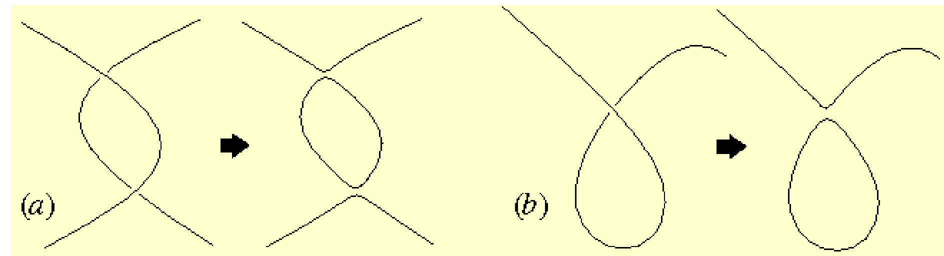


$$V(|\Phi|)=(|\Phi|-\eta_v^2)$$

$$|\Phi|=\eta_v$$

Fig : String formation in the "Mexican-hat" potential

Loops formation



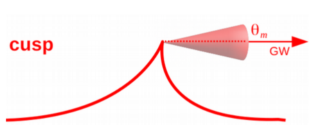
- A network of cosmic strings is characterized by :

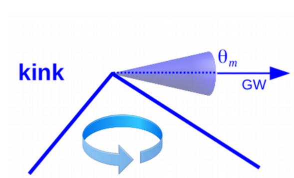
  - string tension Gμ.

  - probability that they interact p

  (String theory : cosmics super string, p < 1)

- cusps and kinks produce powerful bursts of Gravitational waves (Gws).





- The waveform is predicted by the theory.

lenght of the loop

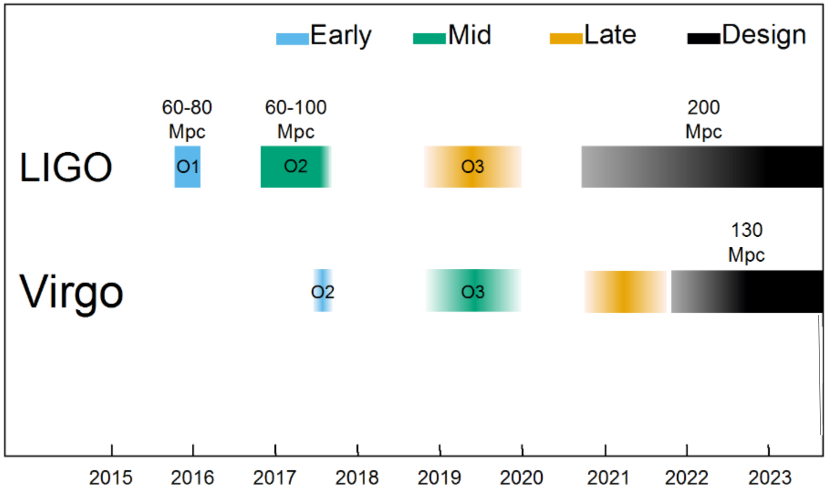
$$h(l,z,f)=A_q(l,z)f^{-q}\Theta(f_h-f)$$

$$A_q(l,z)=g_1\frac{G\mu l^{2-q}}{(1+z)^{q-1}r(z)}$$

$$q=\frac{4}{3}\rightarrow cusps \qquad q=\frac{5}{3}\rightarrow kinks$$

Network of gravitational-waves detectors

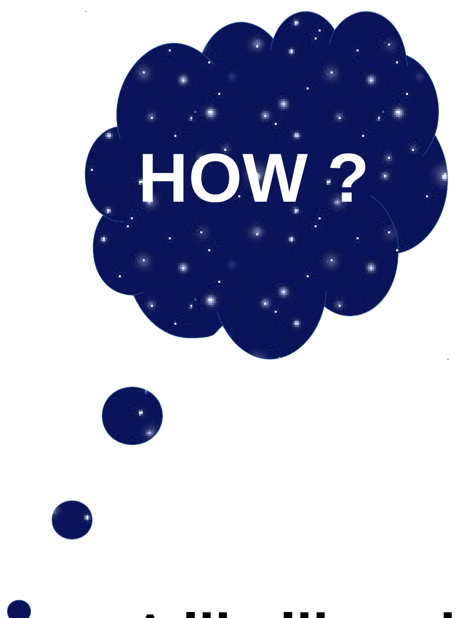
The LIGO Livingston Observatory, LIGO Hanford Observatory, and Virgo



Observing Run (A period of observation in which gravitational wave detectors are taking data) chronology

Pipeline

- We searched the Advanced LIGO (2 interferometers : Hanford **H1**, and Livingston **L1**) O1 data (2015-2016) for individual bursts of GWs from cusps and kinks.



1 **Wiener-filter analysis** to identify events from Hanford and Livingston matching the waveform predicted by the theory.

2

Coincidence (time) to reject a part of the detector noise artifacts.

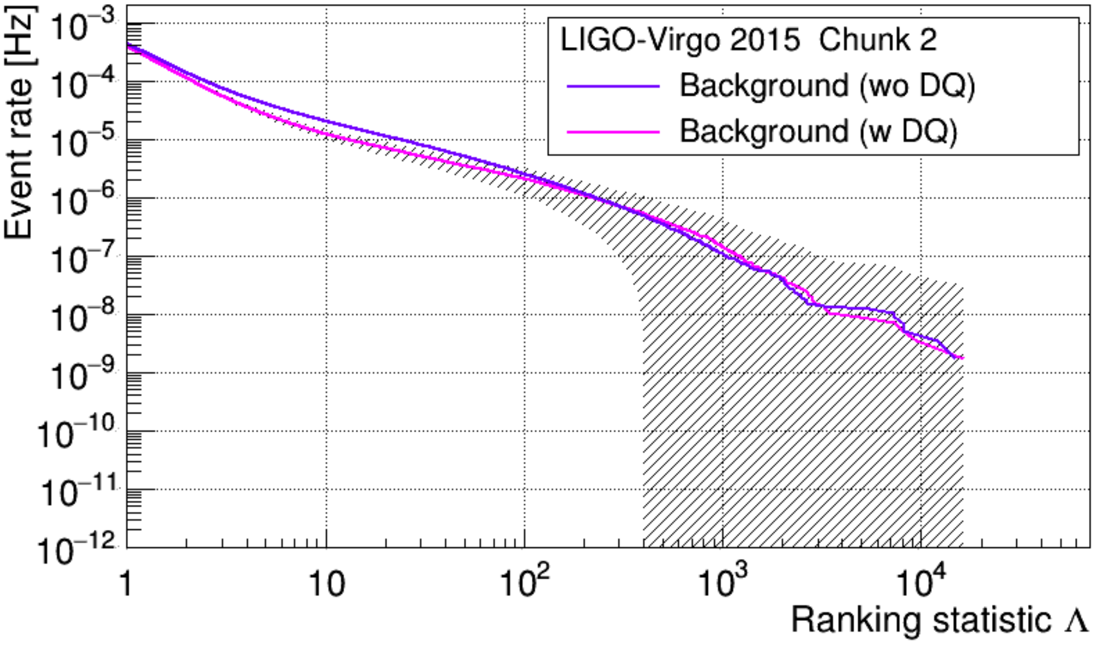
3

A **likelihood ratio** is computed to rank coincident events and infer probability to be signal or noise.

$P(T \in S|\vec{x})$ Is an increasing function of $\Lambda(\vec{x}) = \frac{P(\vec{x}|T \in S)}{P(\vec{x}|T \in N)}$

The signal and the noise …

1/ We perform a blind analysis : Estimate the rate of accidental coincidences the so-called background. It is created by shifting the Livingston triggers sets relative to Hanford and look for coincident events.



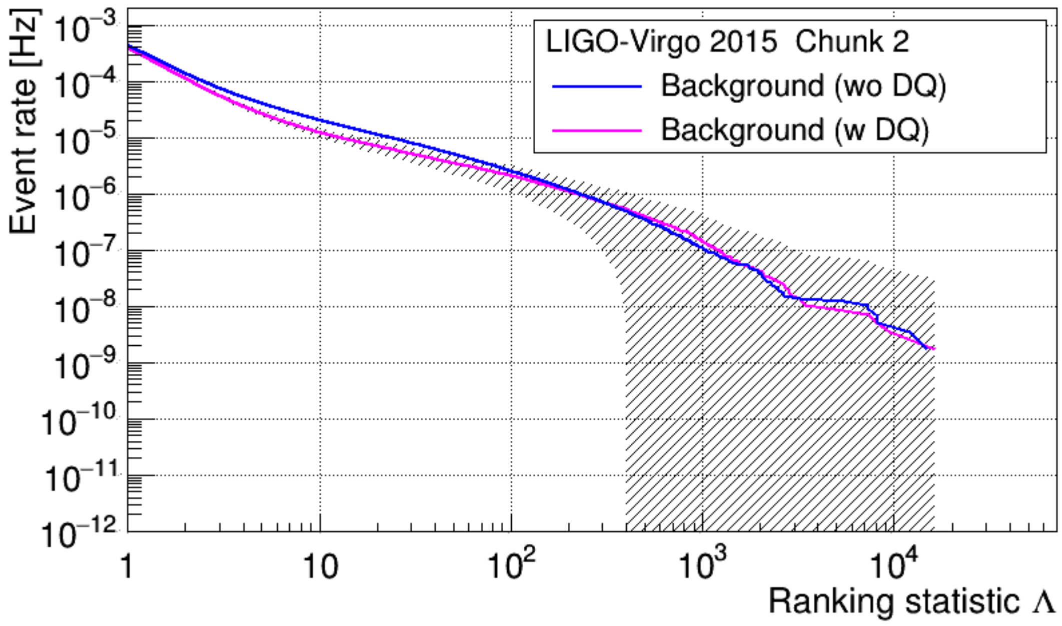
Reminder : high value of Λ means high probability to be the result of a GW.

The signal and the noise …

- **Understanding data quality is very important when working with LIGO data …**

  2 / We tested the impact of flags on the background and some were useful.

  Flags = auxillary channels are used to create data quality flags to note times when the strain data is corrupted by instrumental artifacts.



The signal and the noise …

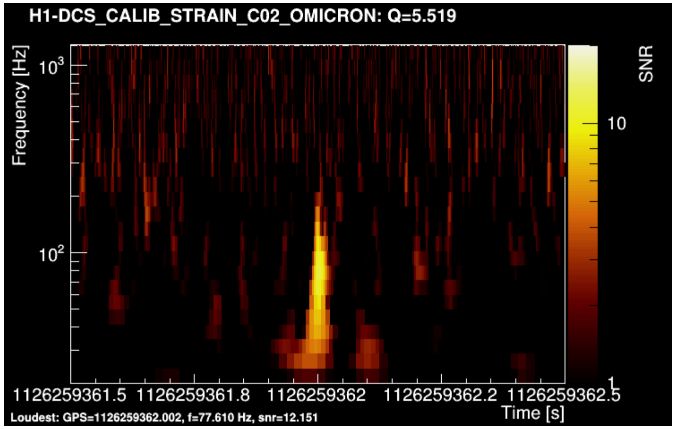
- 3 / We studied the 200 loudest events one by one in order to indentify families of glitches.

  Conclusion : Most of them are transient noise called « blip glitches ».

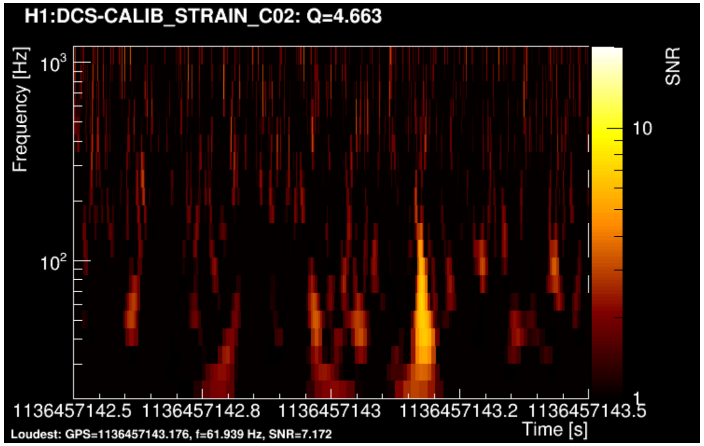
  The LIGO-Virgo collaboration do not understand these glitches.

  → The search is limited by these blip glitches.

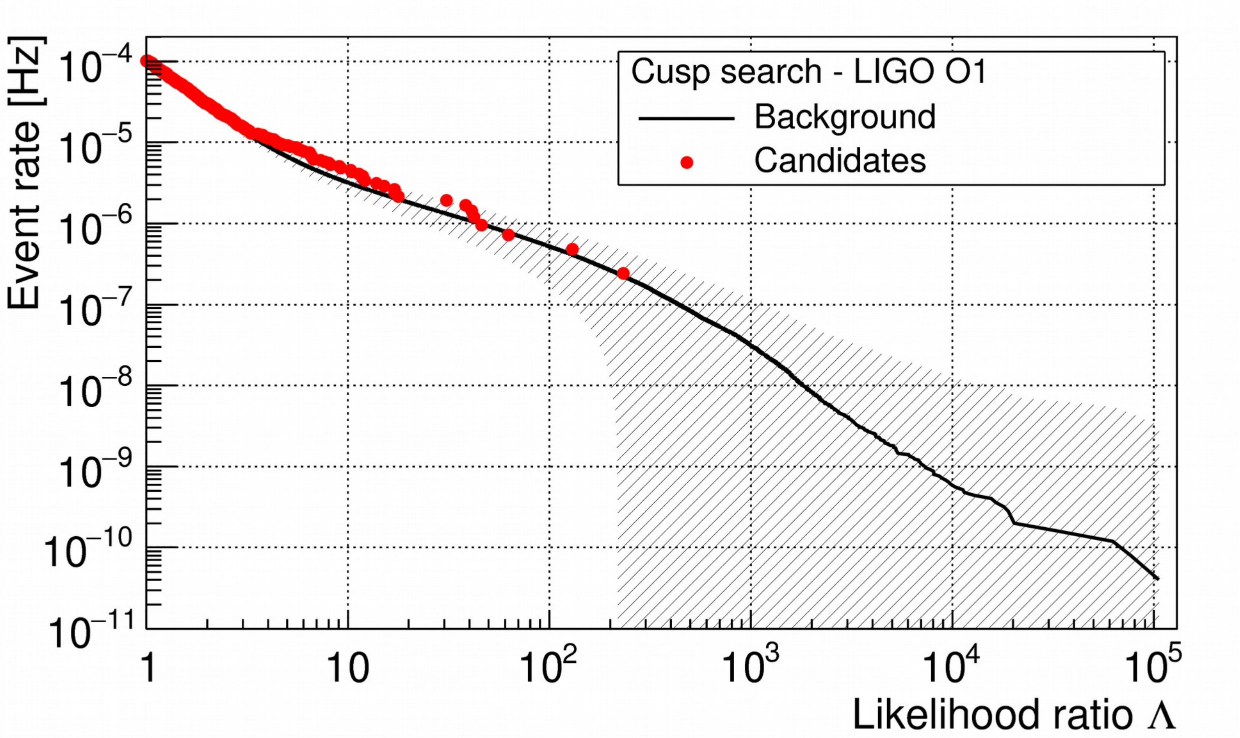
- Injection of a cusp signal (spectrogram)



- Blip glitch



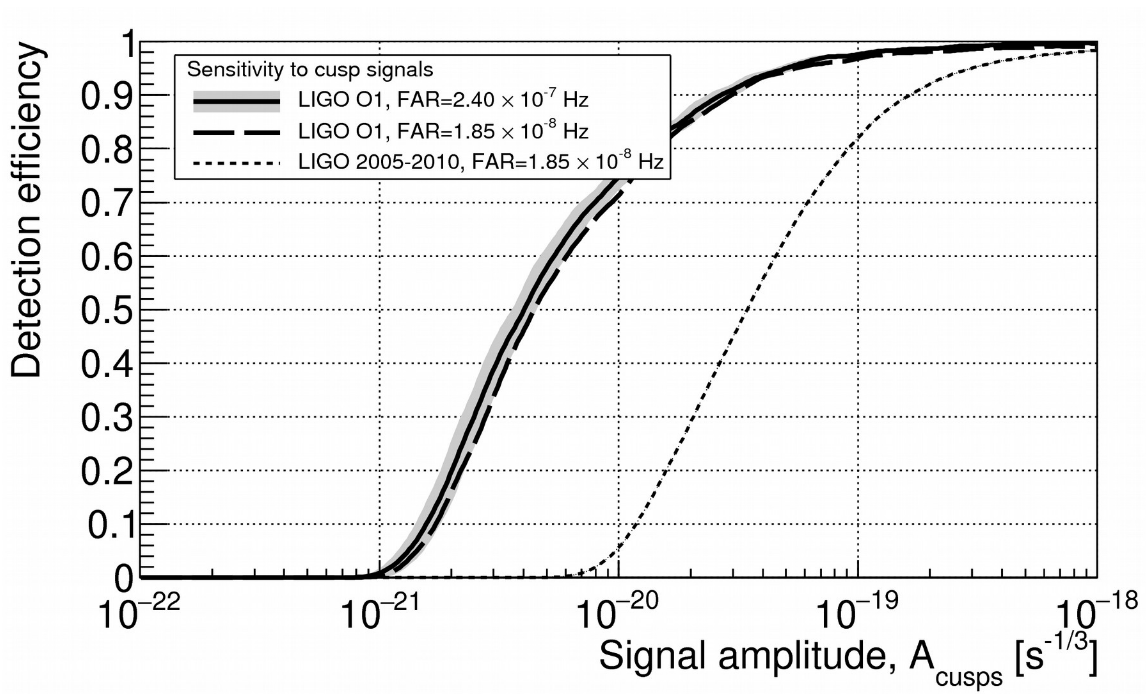
Results : Cusps search



- The black line shows the expected background of the search.
- The red points show the cusp events rate as a function of the likelihood ratio Λ.

→ **The events are consistent with the background.**

Results : Cusp search



- Sensitivity of the search as a function of the cusp signal amplitude. This is measured by the fraction of simulated cusp events recovered with $\Lambda > \Lambda_h$

  (highest ranked event).

- We compared with the sensitivity of the previous LIGO Virgo burst search (run S5/S6 dashed lines).

→ **The sensitivity is improved by a factor 10 !**

Loop models

- We set upper limits on the cosmic string parameters for three recent loop distribution models $n(l,t)$

  → M=1: “original model” Vilenkin/Shellard, updated by Siemens et al.: Phys. Rev. D 73, 105001 (2006)

  → M=2: Olum et al.: Phys. Rev. D89, 023512 (2014)

  → M=3: Ringeval et al.: JCAP 1010, 003 (2010)

  + super-string models, where the reconnection probability $p < 1$.

Parameter constraints

- The parameter space (Gμ ,p) is scanned and the effective rate is computed :

$$R_{eff}(G\mu, p) = \int_0^{\infty} e(z, G\mu) \frac{dR(A, G\mu, p)}{dA} dA$$

Important difference between models :

- For M1 and M2, the distribution is dominated by large loops and differs by the value of a factor of renormalization.
- For M3 if we fixe the value of Gμ there is ~10^4 more very small loops then in the others models, so the observation of small loop is favored.

Upper limits

→ The excluded regions are below the respective curves.

All the experimental results are complementary as they probe different regions of the loop distributions. (different z)

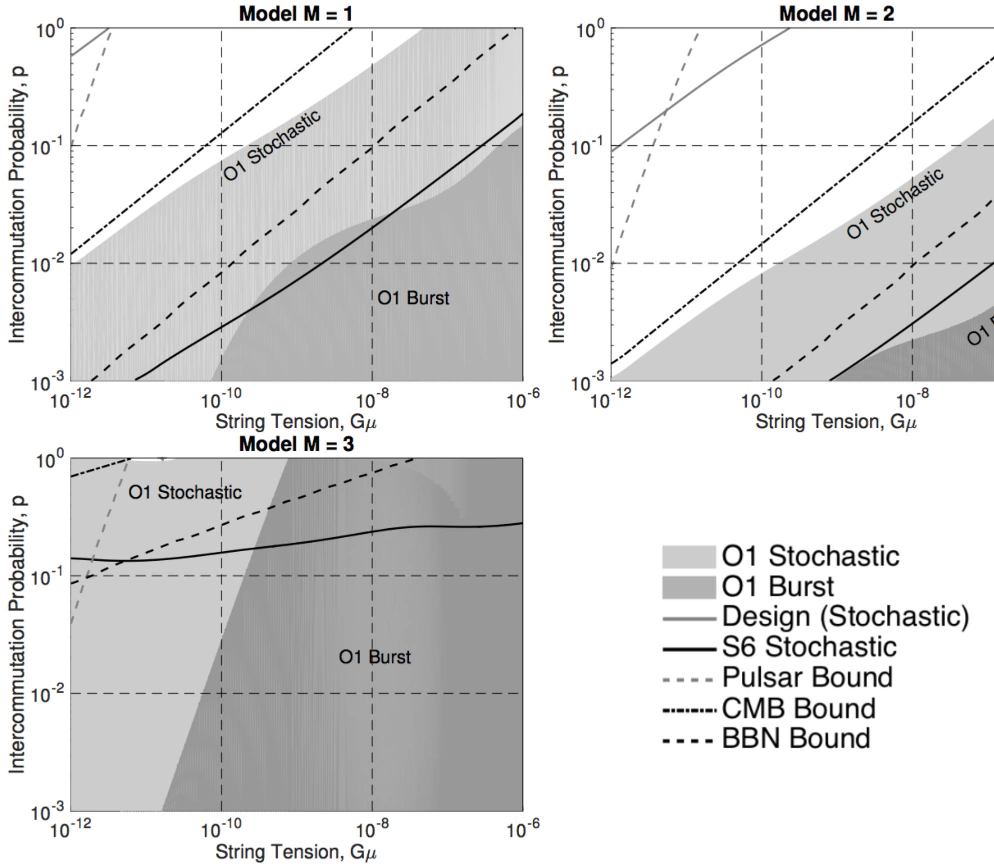


Fig : Exclusion regions are shown for three loop distribution models.
Shaded regions are excluded by the latest (O1) Advanced LIGO stochastic and burst measurements.
We also show the bounds from the previous LIGO-Virgo stochastic measurement, from the indirect BBN and CMB bounds and Pulsar bounds.

- Paper published : https://journals.aps.org/prd/abstract/10.1103/PhysRevD.97.102002

To conclude …

- Today :

  - Same work for the run O2. We run a first analysis including the Virgo data, but our efforts were not useful. Virgo was not enough sensible and so we did not include Virgo data in the final analysis.

  - The results will be published soon.

- Next O3 preparation

  - Use LIGO-Virgo data

  - New models to test

  - Combine the stochastic and burst upper limits

  - In the case of a detection during O3 run, I am going to work on parameter estimation.

- Thank you !