Search for unmodeled long duration gravitational waves for Advanced LIGO and Advanced Virgo's third observing run

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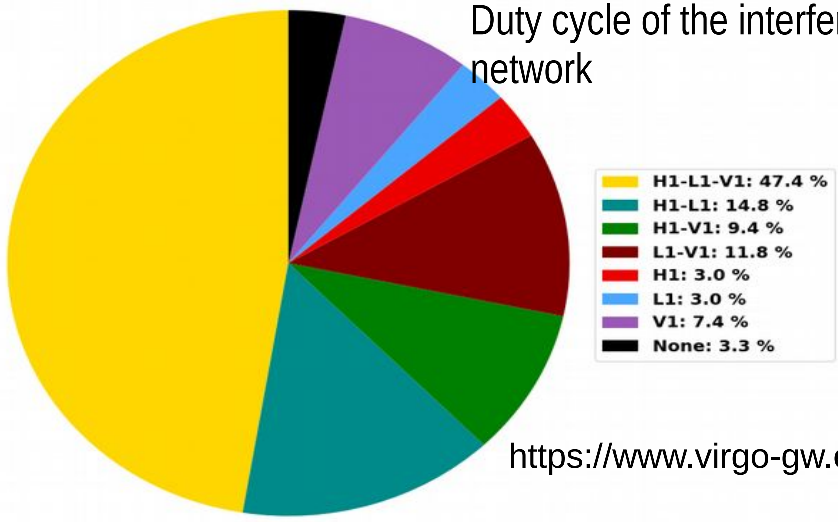
Outline

- Third Advanced LIGO and Advanced Virgo observational run
- All-sky search for long-duration gravitational wave bursts
- Search results and sensitivity

O3 observing run

Three observing runs have happened to date:
O1: 12 Sep 2015 -20 Oct 2015
O2: 30 Nov 2016 - Aug 25th
O3a: 1 Apr 2019 - 1 Oct 2019
O3b: 1 Nov 2019 - 27 Mar 2020
O3b data taking ended due to the impact of COVID-19

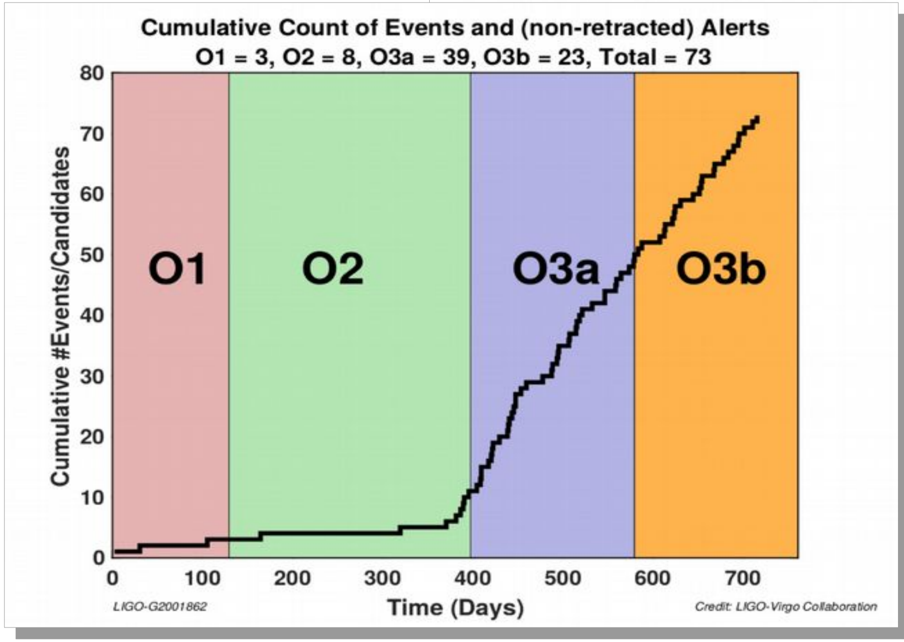
Duty cycle of the interferometer network



https://www.virgo-gw.eu/status.html

The sensitivity, quantified by Binary neutron star inspiral range:

- Hanford: 115 Mpc
- Livigstone 133 Mpc
- Virgo: 50 Mpc



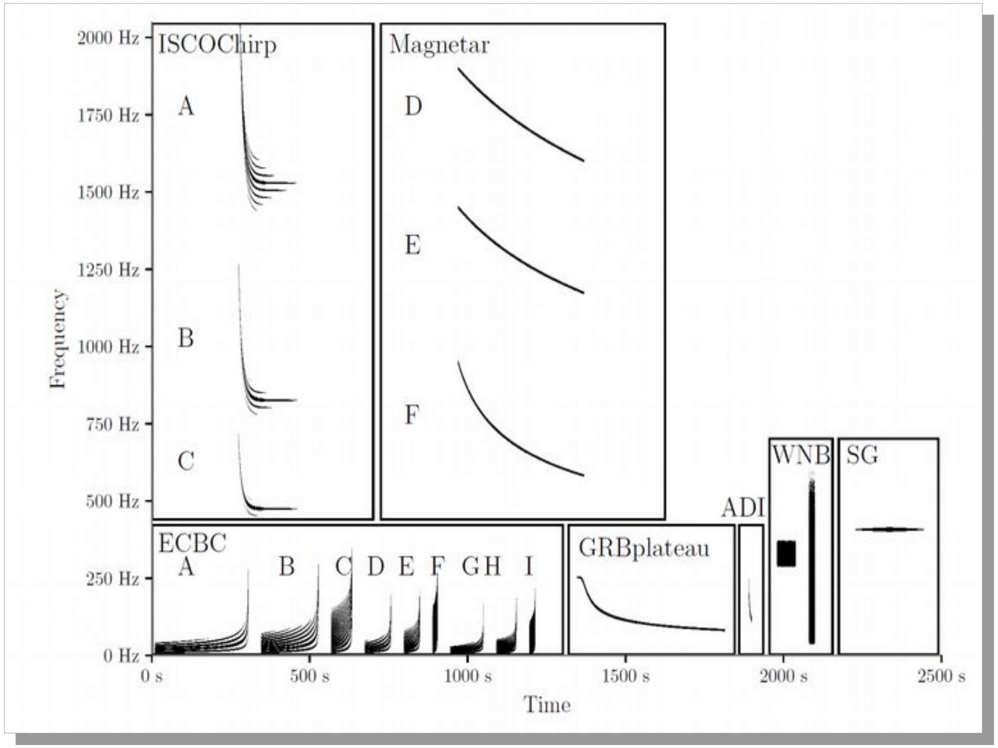
Compact binaries coalescence:

- O1-O2: detection ~every few months
- O3: detection ~weekly

Astrophysics sources

Searches for “long" (> 1 s) duration signals cover a variety of astrophysical phenomena:

- newborn neutron stars from BNS merger or core-collapse supernovae, fallback accretion, MHD instabilities, non-axisymmetric deformations
- accretion disk fragmentation and instabilities around black holes
- flares from isolated magnetars (Soft Gamma Repeaters, anomalous X-ray pulsars);
- Eccentric compact binary coalescences...



Gravitational waves originated by these astrophysics processes are not fully modeled and cover wide morphology range

↓

Unmodelled searches

The ISCOChirp waveforms have been shifted up in frequency by 50 Hz for readability.

Search algorithms

Unmodelled searches employ minimal or no assumption on the looked for signal:

- Select excess power in time-frequency representation of the data, coincidentally and/or coherently in different interferometers
- The distribution of background events is estimated using the time-slides method
- Triggers are assigned a false-alarm rate (FAR) and a p-value based on the background distribution of the detection statistic

Algorithms employ in the search:

- STAMP-AS: identify clusters of excess cross-power in time-frequency maps, detection statistic based on the total cross-power.
  - Zebragard : seed-based clustering - groups neighbouring excess power pixels.
  - Lonetrack : seedless clustering - looks for tracks of pixels with a Bezier curve shape.
- Coherent WaveBurst (cWB) : maximum likelihood approach on coherent multi-resolution time-frequency maps with selection of triggers based on duration and coherence.
  - specific configuration for long duration unmodeled signal

Searches results

- 204.4 days of coincident LIGO data from Hanford (H1) and Livingston (L1)
- only coincident data from LIGO detectors are used, (the Virgo data would not improve the sensitivity)
- all-sky search, signal duration 2 - 500 s and frequency range 24 - 2048 Hz .

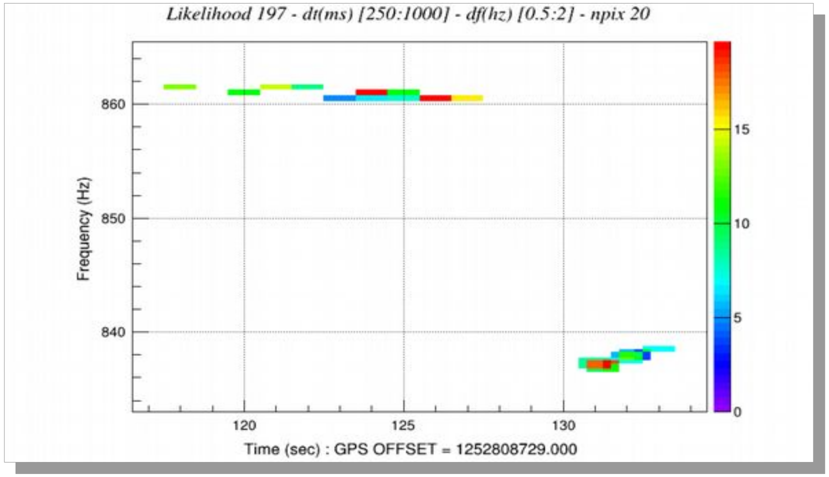
No significant trigger was found.

most significant coincident triggers found by each of the pipelines

Pipeline	FAR [Hz]	p-value	Frequency [Hz]	Duration [s]	Time [GPS]
cWB	1.0×10^{-8}	0.088	838-861	16	1252808855
Zebragard	5.6×10^{-8}	0.40	1650-1769	21	1244819393
Lonetrack	1.7×10^{-8}	0.14	1510-1937	417	1253105020

Most signicant event found by cWB with FAR 1/3.09 yr^{-1} (1.7 σ)

It shows a time frequency map composed of two separated cluster of excess power pixels (belonging to two different non stationary spectral lines)



Sensitivity search

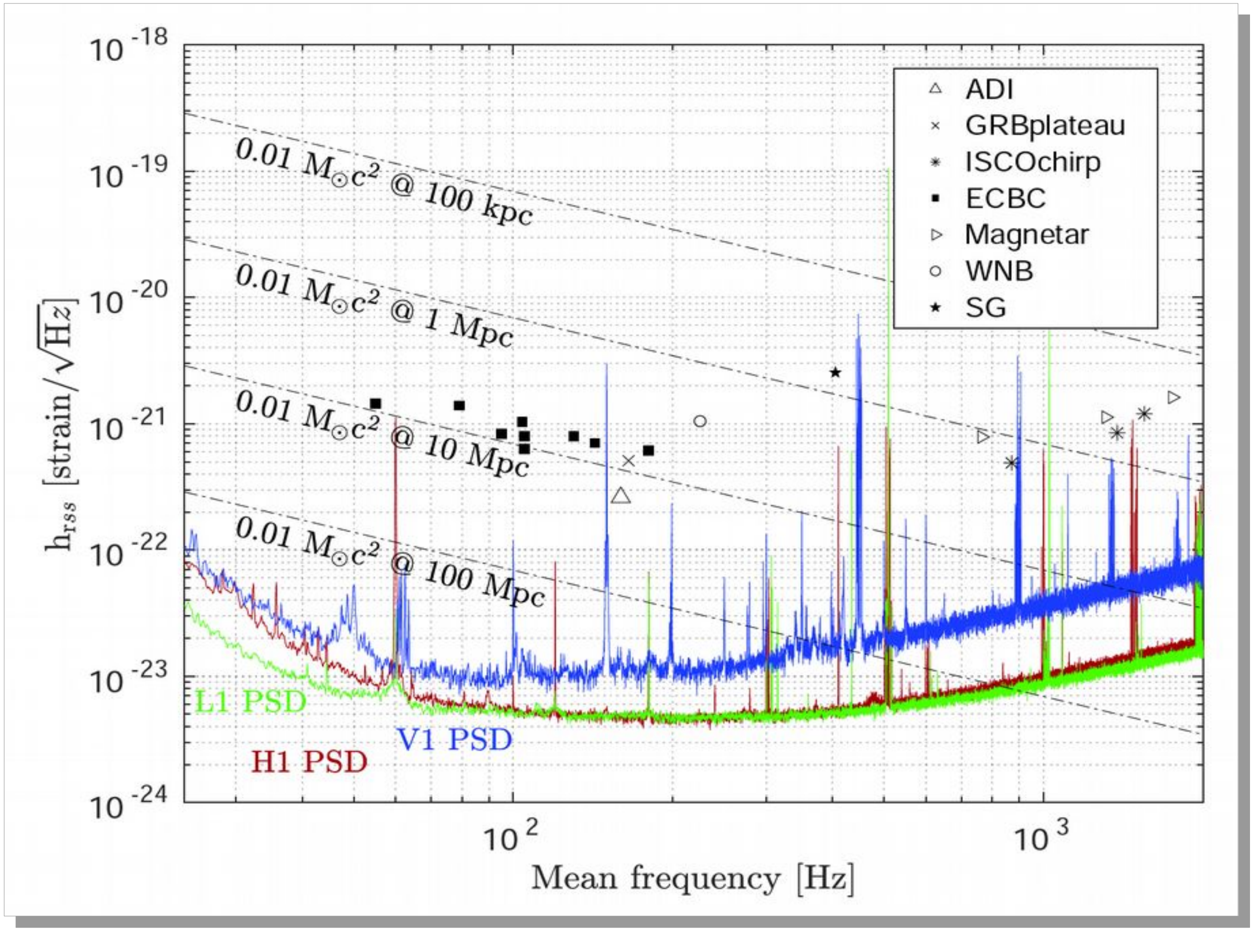
sensitivity search estimated by injecting simulated signals in O3 data at random time, sky location and polarization.
FAR threshold applied to recovered signal. FAR< 1/50 yr^{-1}

Astrophysical waveforms:

- post-merger magnetars (Magnetar)
- accretion disk instabilities (ADI);
- eccentric compact binary coalescences (ECBC);
- broadband ISCO waves around Kerr black holes (ISCOchirp);
- Newly formed magnetar associated with GRB plateau

Ad hoc waveforms:

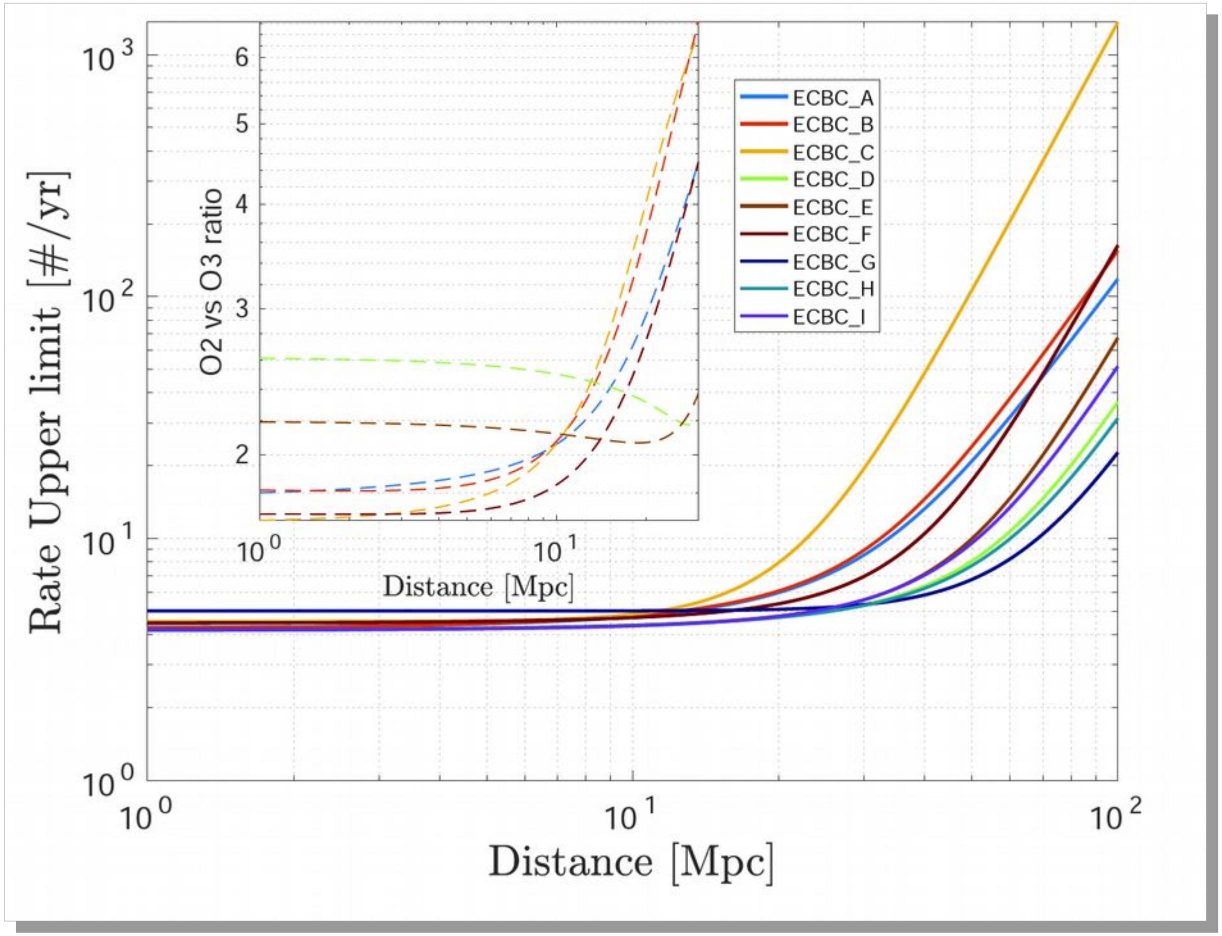
- Sine-Gaussian signal (SG)
- White noise burst (WNB)



Rate upper limit on eccentric binary coaelscences

Rate upper limits (at 90% confidence level) of eccentric compact binary coalescences:

- 400 -3200 $Gpc^3\ yr^{-1}$ (depending on masses and eccentricity)
- 1.5 - 2 times lower than the ones computed for O2
.
- Estimated merger rates from the second LIGO-Virgo GW transient catalogue (GWTC-2):
  $23.9^{+14.3}_{-8.6}$ $Gpc^3\ yr^{-1}$ for BBH
  340^{+490}_{-240} $Gpc^3\ yr^{-1}$ for BNS



Conclusions

- Long duration unmodeled search on O3 data is completed: no detection found.
- Sensitivity increased by 1.5 – 2 with respect O2 (compatible with increased detector sensitivity).

- For future data takings it is foreseen to integrate Advanced Virgo in the search and the interferometers sensitivity is expected to increase of a factor ~1.5 in O4 and ~2 in O5.
- It is expected to improve search algorithms sensitivity, and expand search parameter space.

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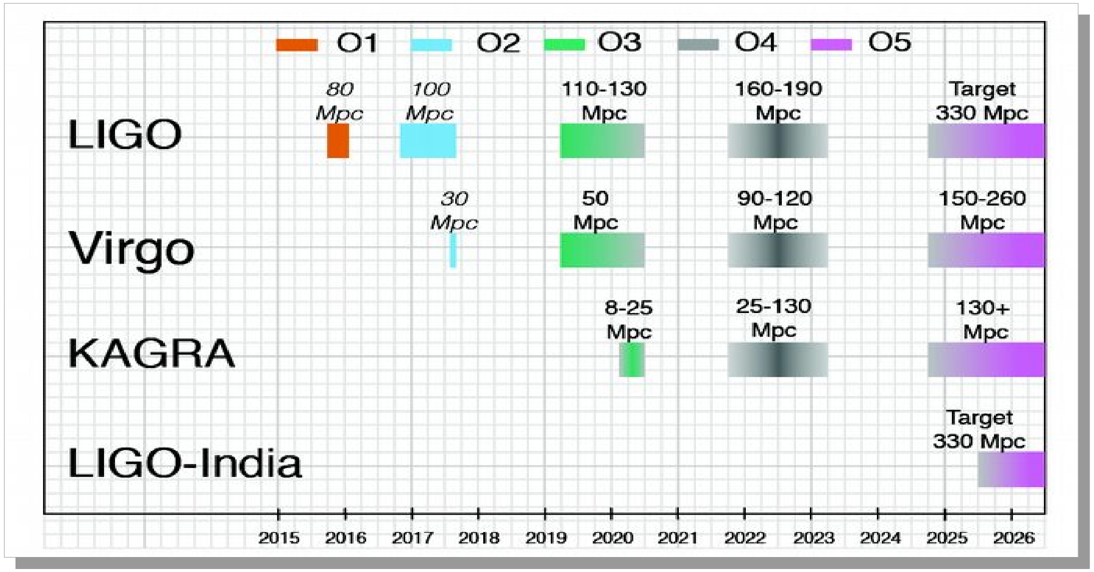
Back up

Interferometers networks near future



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2022 O4: four-detector network

Late 2024/Early 2025 – 2026 O5: O5 will begin with a four-detector network incorporating the A+ upgrade for the aLIGO instruments and the AdV+ Phase 2 upgrade for Virgo.

Hardware update (Frequency independent squeezing, newtonian noise subtraction, improved coatings) will allow improvement in spectral sensitivity (low and high frequency)