GWODW - 2025

Introduction to Fourier analysis, noise sources, and accessing open data

Lecture - 2

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12 May 2025

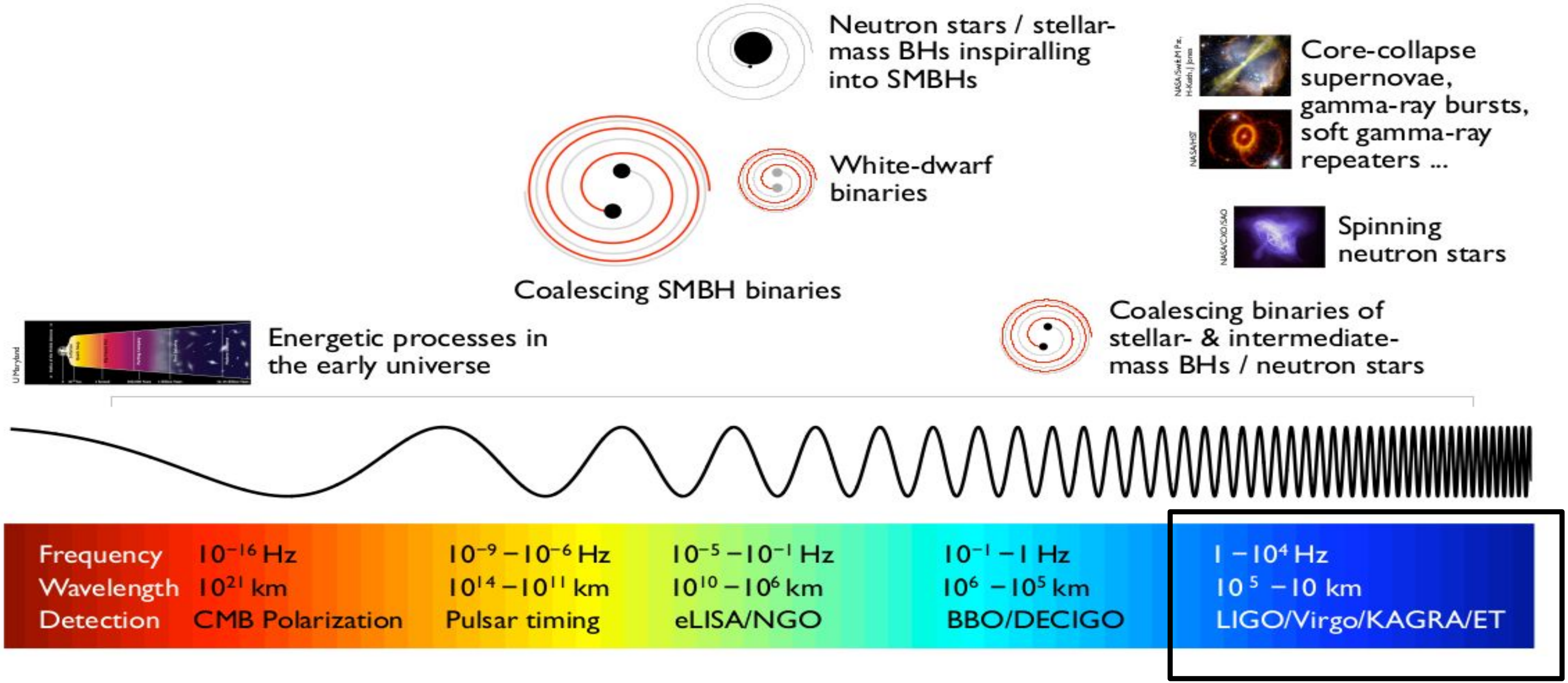
INTERNATIONAL CENTRE for THEORETICAL SCIENCES

TATA INSTITUTE OF FUNDAMENTAL RESEARCH

Outline

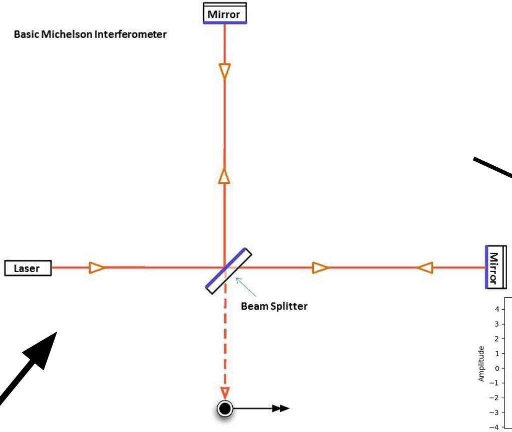
- Short recap of last lecture
- Attaining gw sensitivity - noise modelling
- Fourier transform, windowing, power spectral density
- Detector noises - current scenario
- Non-stationarities - alternative approaches
- Introduction to open data

Gravitational wave spectrum

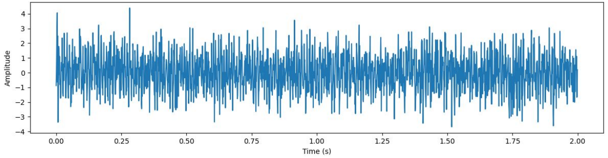


Credit : P. Ajith

Interferometer strain data output



$$h = \frac{\Delta l}{l}$$

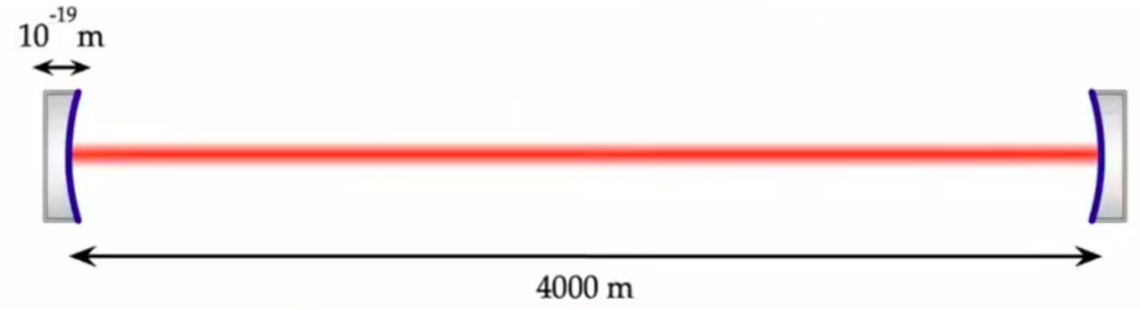


h(t) = s(t) + n(t)

signal **noise**

https://www.ligo.caltech.edu/page/ligos-ifo

Interferometer strain data output



h(t) = s(t) + n(t)

$$\boxed{h = \frac{\Delta l}{l}}$$

Output strain data amplitude ~ 10^{-21}

But how to measure this ???

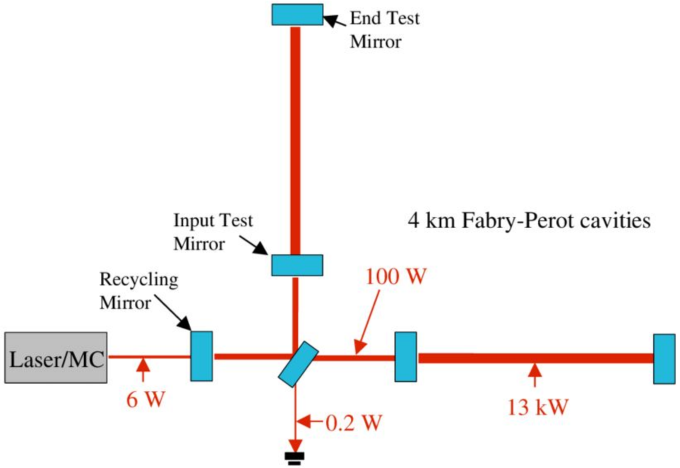
Interferometers for GW detection

- Strain sensitivity of simple Michelson $\longrightarrow$ $h := \frac{\Delta l}{l} \sim \frac{\lambda_{laser}}{l} \sim \frac{10^{-6} m}{10^{3} m} = 10^{-9}$

Interferometers for GW detection

- Strain sensitivity of simple Michelson ⟶ $h := \frac{\Delta l}{l} \sim \frac{\lambda_{laser}}{l} \sim \frac{10^{-6}m}{10^{3}m} = 10^{-9}$

- Increase effective path length by bouncing the beam (~1000 times) ⟶ $h \sim \frac{\Delta l}{l_{eff}} \sim \frac{\lambda_{laser}}{\lambda_{GW}} \sim \frac{10^{-6}m}{10^{6}m} = 10^{-12}$



Hamilton+, 2005

Interferometers for GW detection

- Strain sensitivity of simple Michelson → $h := \frac{\Delta l}{l} \sim \frac{\lambda_{laser}}{l} \sim \frac{10^{-6}m}{10^3 m} = 10^{-9}$
- Increase effective path length by bouncing the beam (~1000 times) → $h \sim \frac{\Delta l}{l_{eff}} \sim \frac{\lambda_{laser}}{\lambda_{GW}} \sim \frac{10^{-6}m}{10^6 m} = 10^{-12}$
- Measure a fraction of fringe width. Limited by intensity fluctuations in laser (number fluctuations of photons)

Can measure → $\boxed{\frac{\Delta l}{\lambda_{laser}} \sim \frac{1}{\sqrt{N_{photons}}}}$

$$P_{laser} = 1W, \lambda_{laser} = 1\mu m, f_{GW} \sim 300Hz$$

Photons collected during one GW cycle

$$\boxed{N_{photons} = \frac{P_{laser}}{hc/\lambda_{laser}}\tau \sim \frac{P_{laser}}{hc/\lambda_{laser}}\frac{1}{f_{GW}} \sim 10^{16}}$$

Interferometers for GW detection

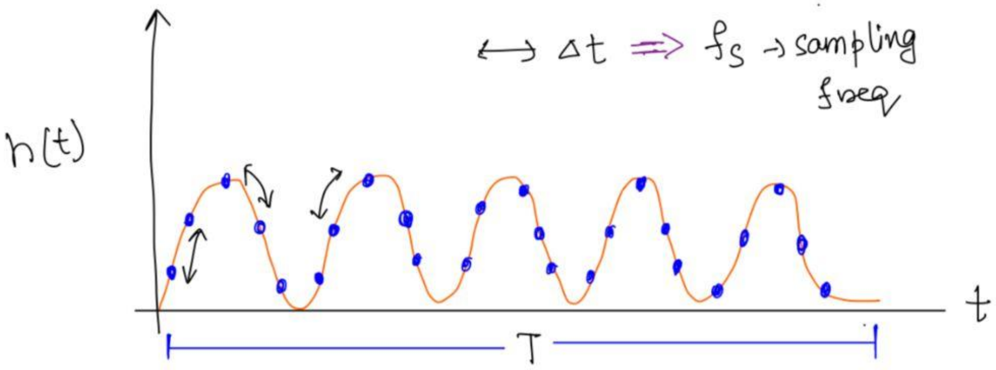
- Strain sensitivity of simple Michelson ⟶ $h := \frac{\Delta l}{l} \sim \frac{\lambda_{laser}}{l} \sim \frac{10^{-6} m}{10^{3} m} = 10^{-9}$
- Increase effective path length by bouncing the beam (~1000 times) ⟶ $h \sim \frac{\Delta l}{l_{eff}} \sim \frac{\lambda_{laser}}{\lambda_{GW}} \sim \frac{10^{-6} m}{10^{6} m} = 10^{-12}$
- Measure a fraction of fringe width. Limited by intensity fluctuations in laser (number fluctuations of photons) ⟶ $h \sim \frac{\Delta l}{l_{eff}} \sim \frac{N_{photons}^{-1/2} \lambda_{laser}}{\lambda_{GW}} \sim \frac{10^{-8} \times 10^{-6} m}{10^{6} m} = 10^{-20}$
- Improve laser power
- Advanced interferometry

Required sensitivity

Nyquist frequency, Nyquist - Shannon Sampling Theorem

Continuous signal $\longrightarrow$ **discrete points** or **samples**

Higher sampling rate $\longrightarrow$ more accurate information and signal reconstruction



Minimum necessary sampling frequency ???

Nyquist frequency, Nyquist - Shannon Sampling Theorem

Continuous signal $\longrightarrow$ **discrete points** or **samples**

Higher sampling rate $\longrightarrow$ more accurate information and signal reconstruction

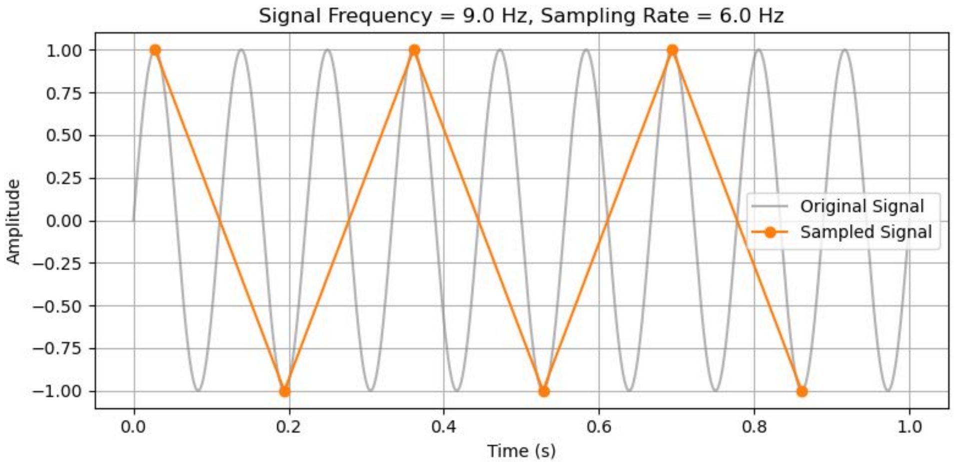
Minimum necessary sampling frequency ???

$\downarrow$

$\boxed{\textbf{Nyquist-Shannon sampling theorem}}$

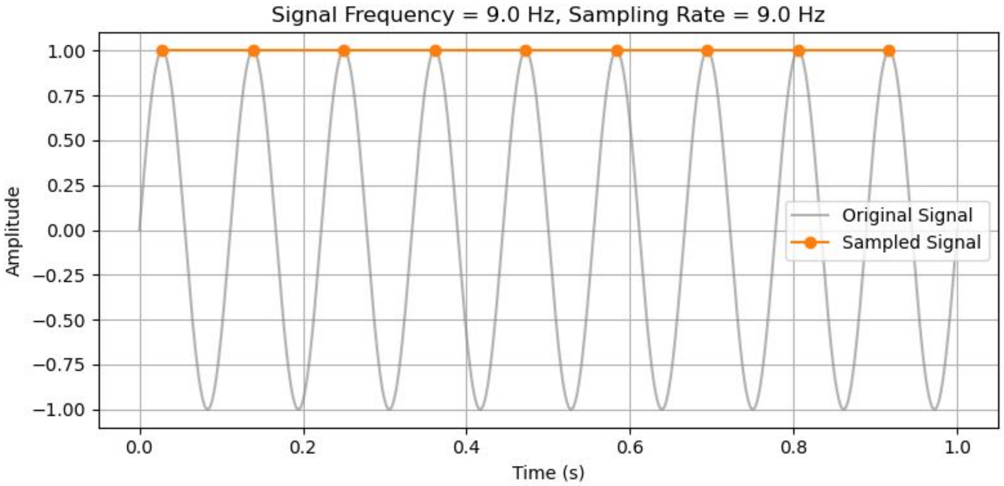
Minimum sampling frequency = 2 x (highest frequency component)

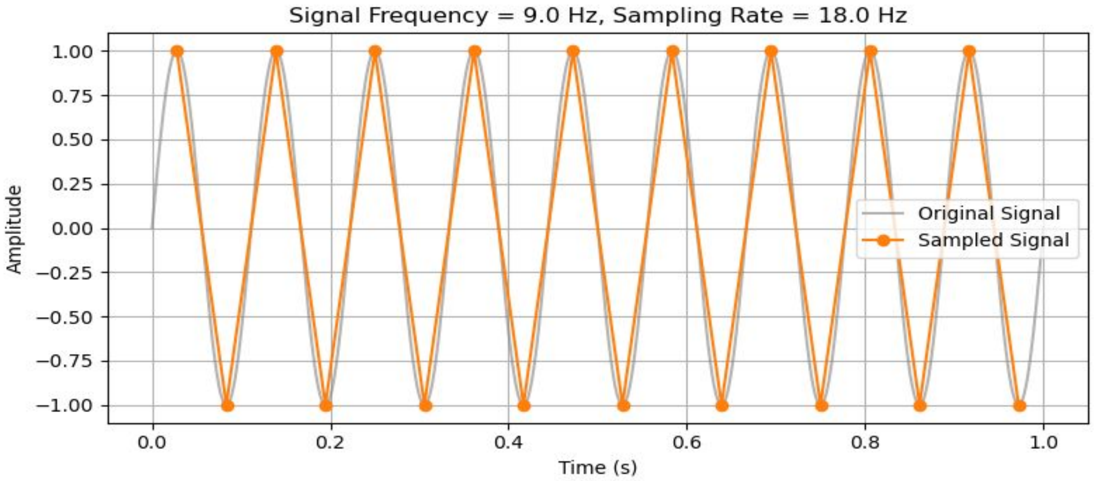
f_S - **sampling frequency**, **critical frequency** (or **Nyquist limit**) $f_N = f_S/2$.


Signal Frequency = 9.0 Hz, Sampling Rate = 6.0 Hz
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Time (s)
Original Signal
Sampled Signal

$$f_s < 2f_N$$

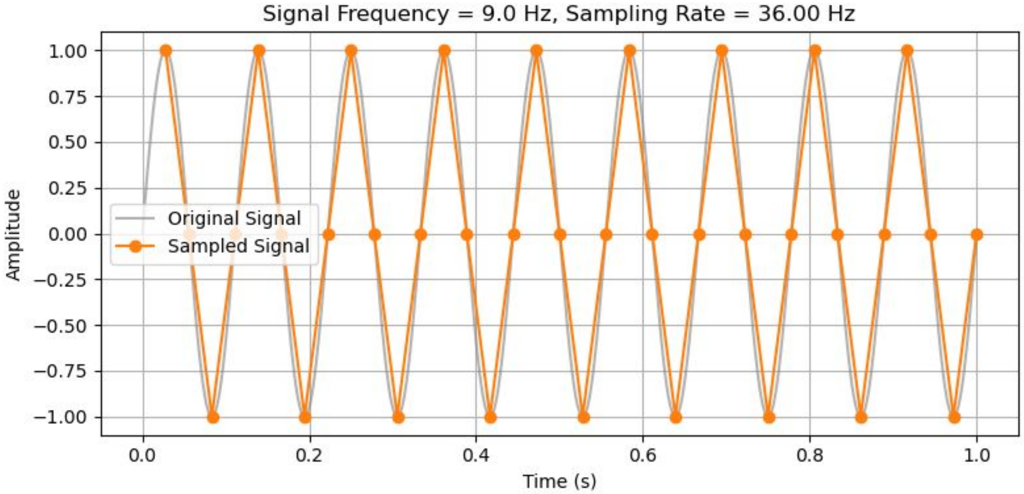
$$f_s = f_N$$


Signal Frequency = 9.0 Hz, Sampling Rate = 9.0 Hz
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Time (s)
Original Signal
Sampled Signal



Signal Frequency = 9.0 Hz, Sampling Rate = 18.0 Hz
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Time (s)
Original Signal
Sampled Signal

$$f_s = 2f_N$$



Signal Frequency = 9.0 Hz, Sampling Rate = 36.00 Hz
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Amplitude
0.0
0.2
0.4
0.6
0.8
1.0
Time (s)
Original Signal
Sampled Signal

$$f_s > 2f_N$$

Order of estimate

T = 100s data, signal freq = 1 kHz, sampling freq = 2kHz

$$f_s = \frac{1}{\Delta t} \longrightarrow \Delta t = \frac{T}{N} \rightarrow N = \frac{T}{\Delta t}$$

$$\boxed{N \sim 10^5}$$

More the length of the signal, more the required number of samples…

Have the strain data from detector…next step????

Analyze it…

Analyzing GW data is tricky

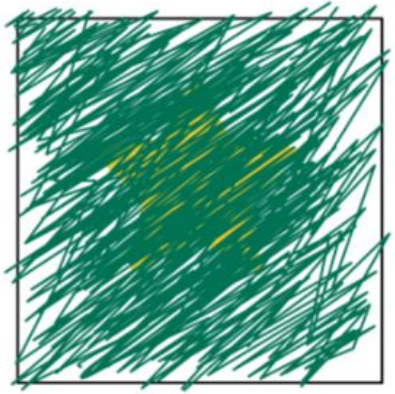
Too weak signal - detector noise overwhelms GW signal

Noise is a random variable - to understand signal, need to understand noise

Further ways of signal identification based on the noise model studied

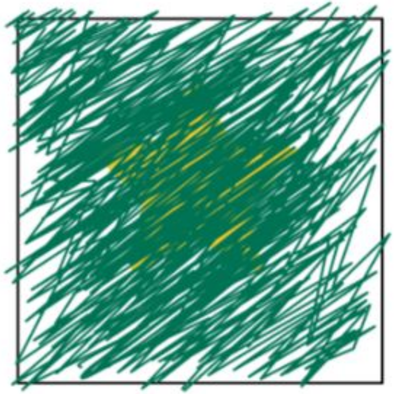
(More details in lecture 4)

Analyzing GW data is tricky



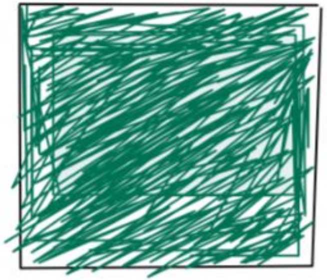
How to understand the underlying image???

Analyzing GW data is tricky

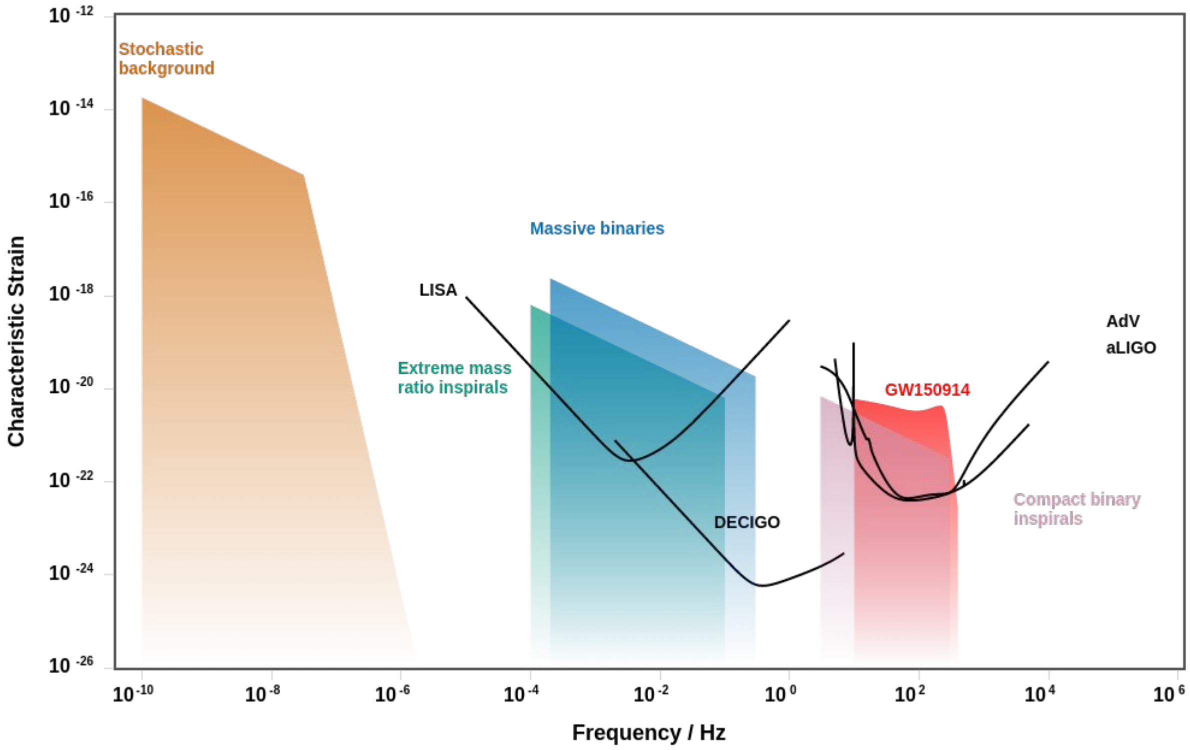


How to understand the underlying image???

Try to understand the noise - rough idea of probable image

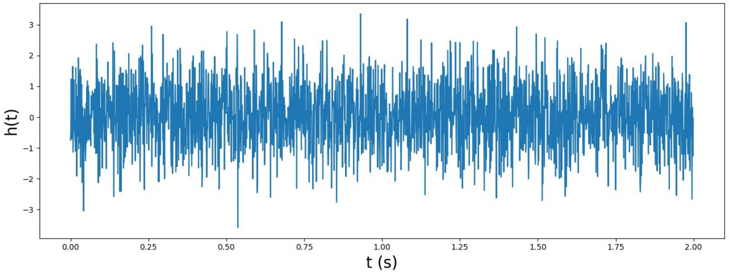


Fourier domain



gwplotter.com

Fourier transform, finite and infinite data



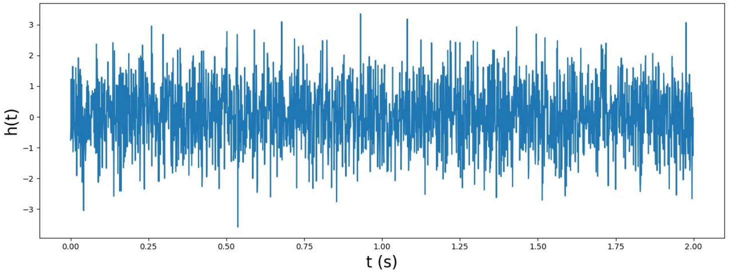
FT

$$\tilde{h}(f) = \int_{-\infty}^{\infty} h(t) e^{-2\pi i f t} dt$$

Limits of integration -> infinity!

Expect an infinite train of data

Fourier transform, finite and infinite data



FT

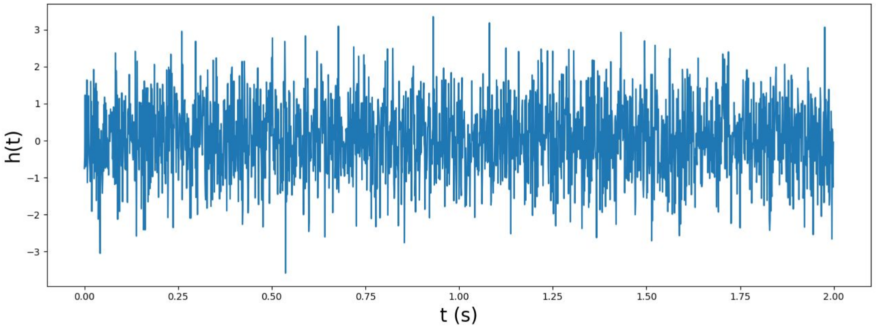
$$\tilde{h}(f) = \int_{-\infty}^{\infty} h(t) e^{-2\pi i f t} dt$$

Limits of integration -> infinity!

Expect an infinite train of data

But in reality we have a finite length of signal with finite time….

Finite and infinite data - Windowing



$$\tilde{h}(f) = \int_0^T h(t) e^{-2\pi i f t} dt$$

T

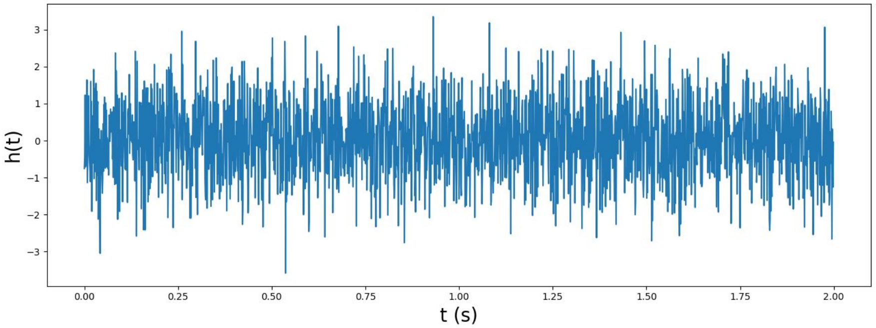
$$\tilde{h}(f) = \int_{-\infty}^{\infty} \boxed{h(t)\omega(t)} e^{-2\pi i f t} dt$$

$$g(t)$$

$$\boxed{\omega(t) = \begin{cases} 1, & \text{if } 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}}$$

Window function

Finite and infinite data - Windowing



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T

$$\omega(t) = \begin{cases} 1, & \text{if } 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$$

$$\tilde{h}(f) = \int_{-\infty}^{\infty} \boxed{h(t)\omega(t)} e^{-2\pi i f t} dt$$

$$g(t)$$

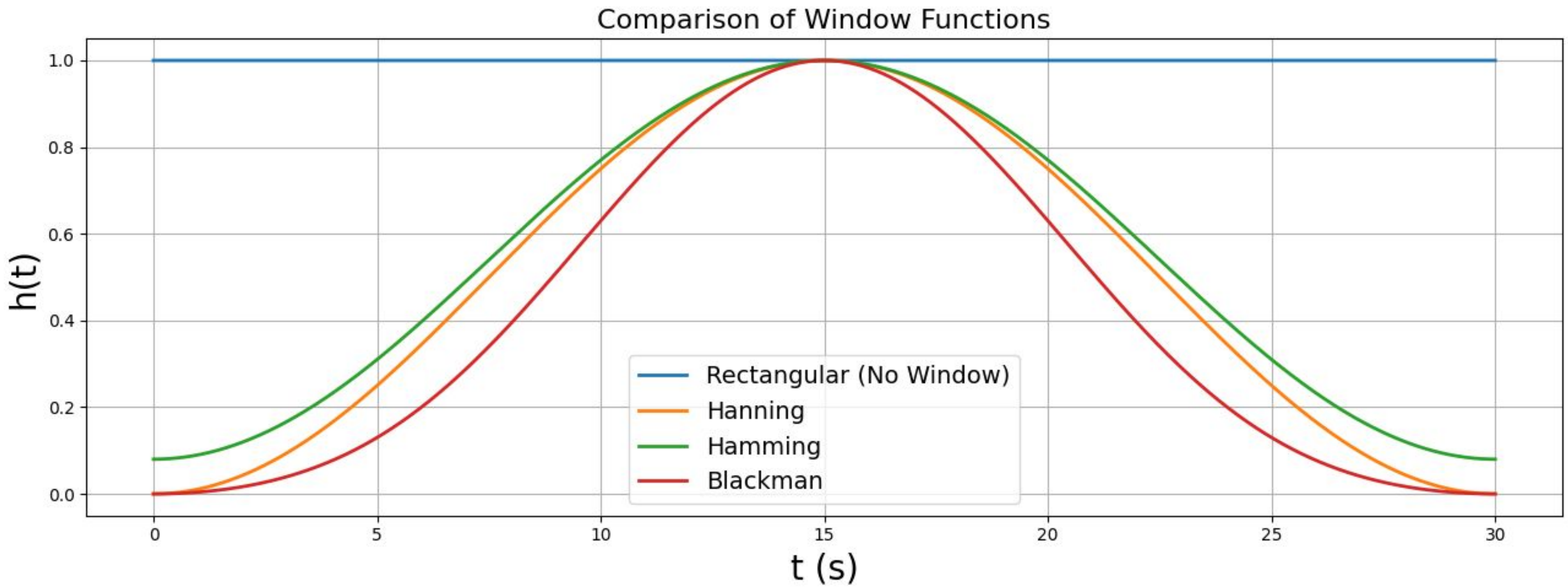
$$\cancel{\mathcal{F}\{h(t)\} = \tilde{h}(f)}$$

$$\mathcal{F}\{g(t)\} = \mathcal{F}\{h(t)\omega(t)\}$$

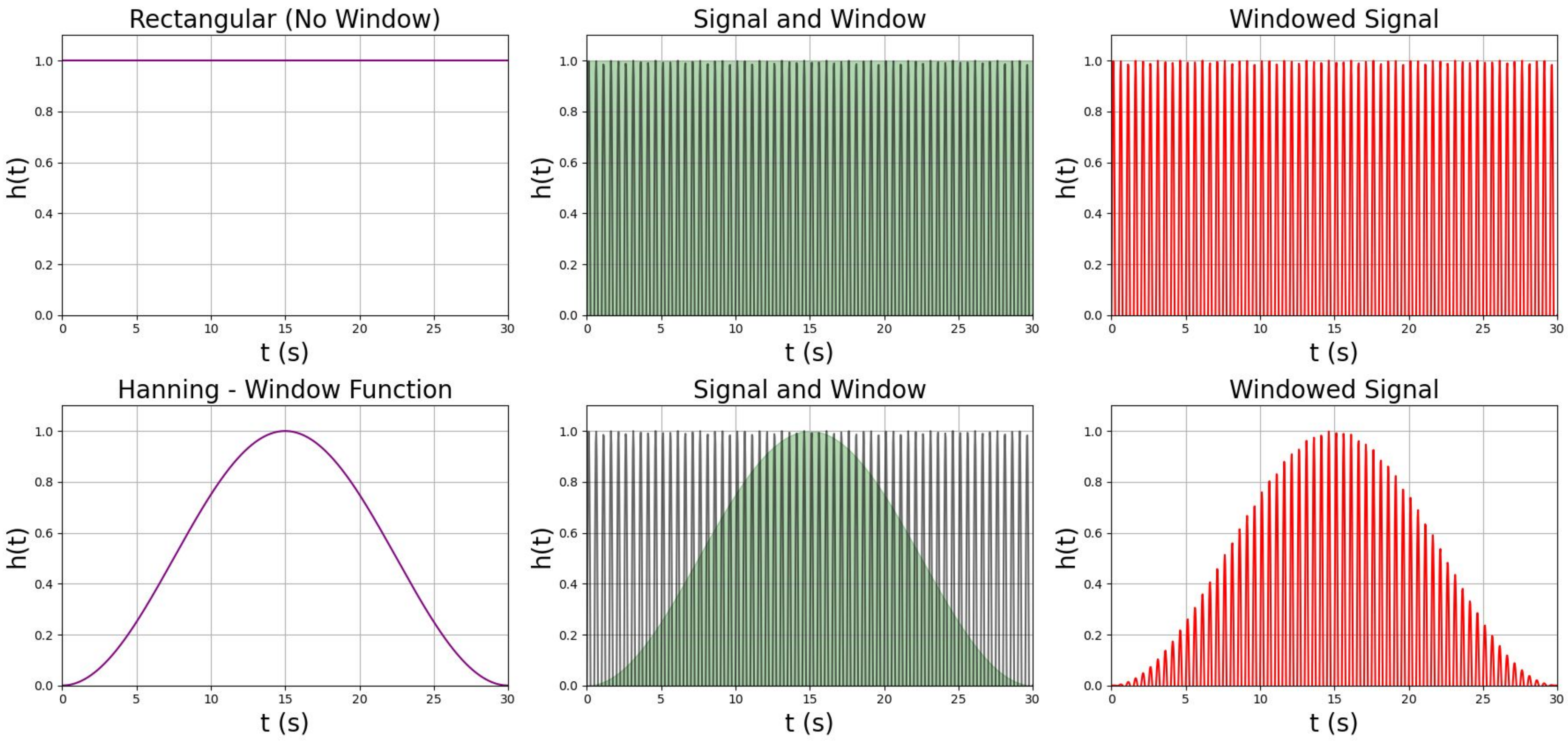
$$\tilde{g}(f) = (\tilde{h} * \tilde{\omega})(f)$$

Windowing

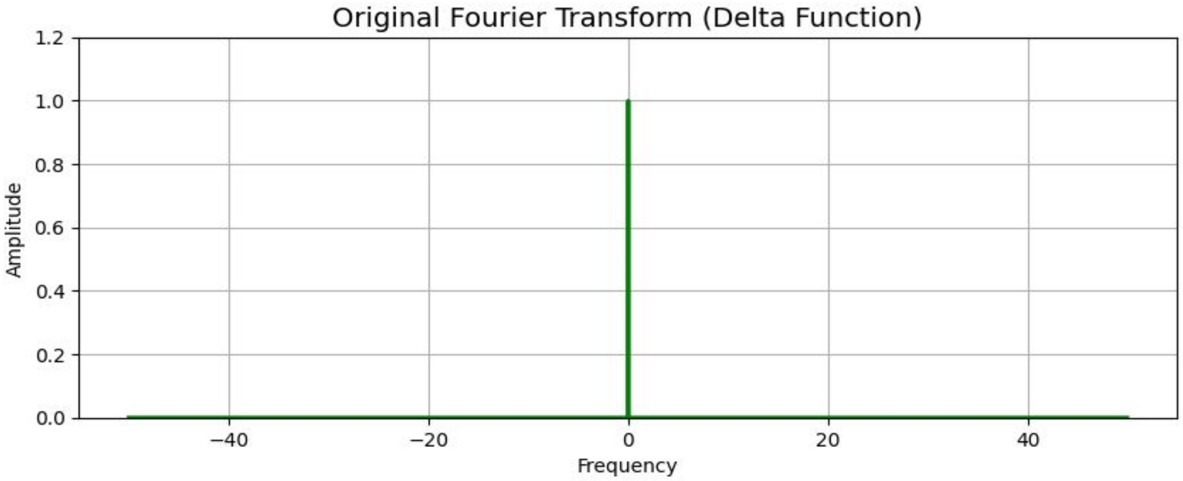
Rectangular | **Hann** | **Hamm** | **Blackman** ....



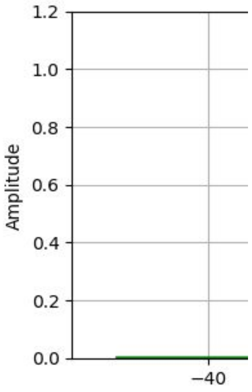
Windowing in action

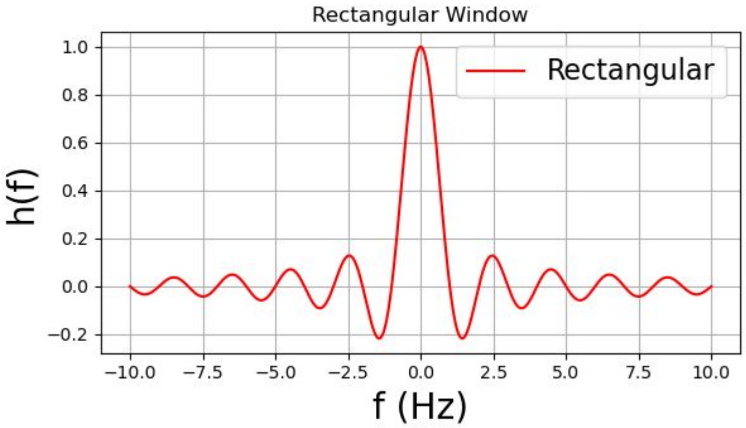


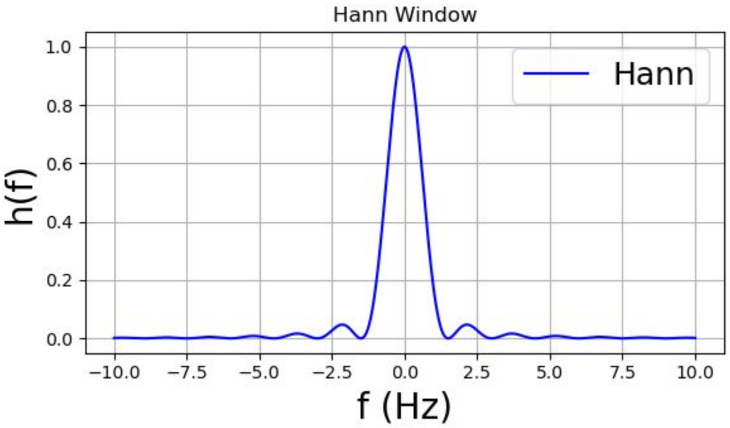
Effect of windowing

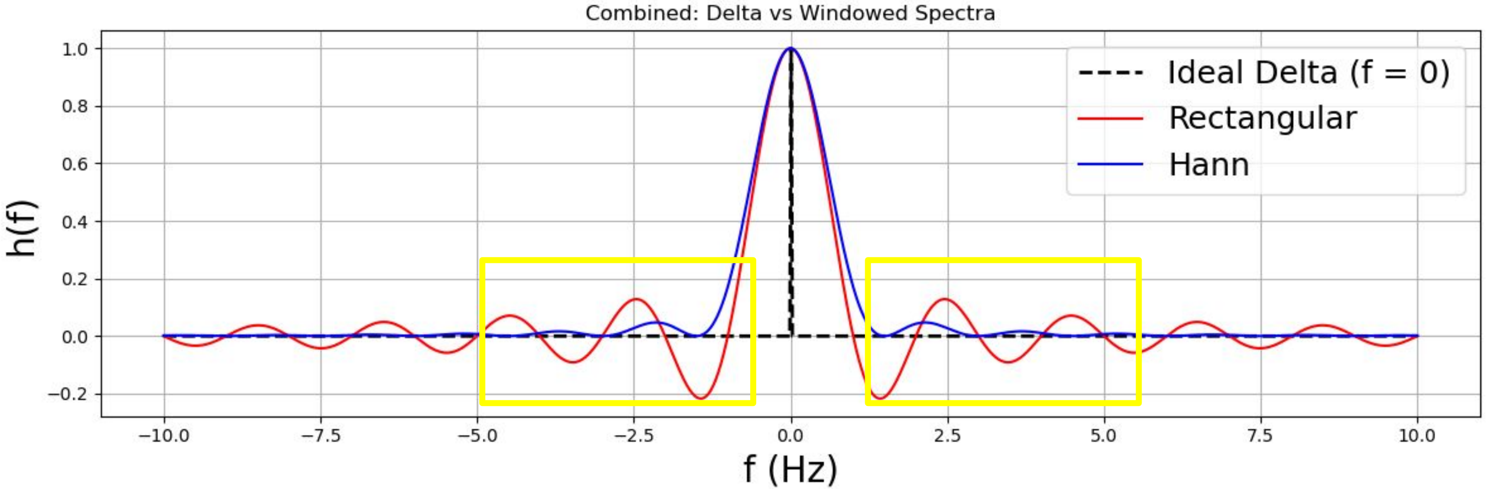


Effect of windowing - Spectral leakage

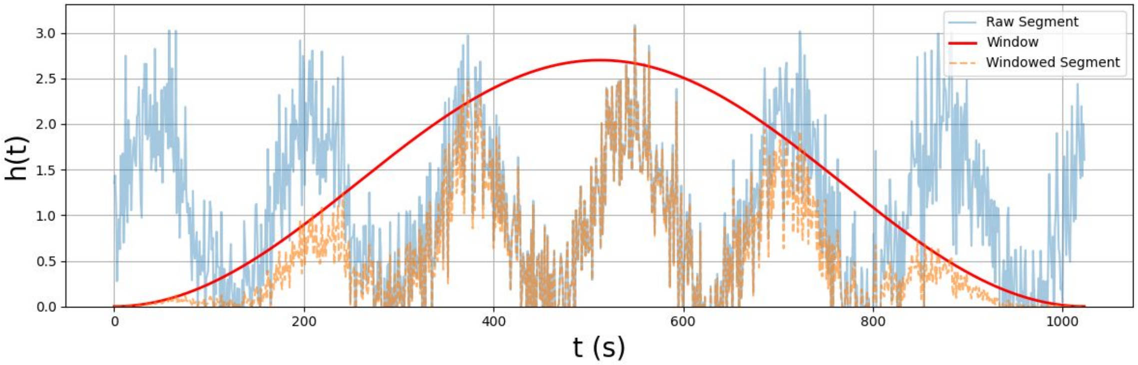








Choosing a window



- Get away with the data discontinuities as much as possible
- Smooth out the fourier transform output
- Windowing attenuating lot of valid data - need to minimize
- Incorporate overlapping techniques to minimize data loss while segmenting

Now let's try to characterize the background noise…

$$\begin{aligned}\langle h^2\rangle &= \lim_{T\to\infty}\frac{1}{T}\int_0^T h^2(t)\,dt = \lim_{T\to\infty}\frac{1}{T}\int_{-\infty}^{\infty} h_T^2(t)\,dt \\ &= \lim_{T\to\infty}\frac{1}{T}\int_{-\infty}^{\infty}|\tilde{h}_T(f)|^2\,df = \lim_{T\to\infty}\frac{1}{T}\int_{-\infty}^{\infty}|\tilde{h}_T(f)|^2\,df \\ &= \lim_{T\to\infty}\frac{2}{T}\int_0^{\infty}|\tilde{h}_T(f)|^2\,df\end{aligned}$$

$$\left[g(t) = h_T(t)\right]$$

At each t, a random variable

$$\boxed{\langle h^2\rangle = \int_0^\infty S_h(f)df}$$

$$\boxed{S_h(f) := \lim_{T\to\infty}\frac{2}{T}\left|\int_0^T h(t)e^{-2\pi i f t}dt\right|^2}$$

Power Spectral Density Estimation

$$S_h(f) = \lim_{T\to\infty} \frac{2}{T} \int_0^T h(t)e^{2\pi i f t}dt \int_0^T h(t')e^{-2\pi i f t'}dt' \qquad \left[t = t' + \tau\right]$$

$$S_h(f) = 2\int_{-\infty}^{\infty} d\tau e^{-2\pi i f \tau} \boxed{\left[\lim_{T\to\infty} \int_0^T h(t')h(t'+\tau)dt'\right]} \longrightarrow R(\tau)$$

$$S_h(f) = 2\int_{-\infty}^{\infty} \boxed{R(\tau)} e^{-2\pi i f \tau} d\tau$$

Autocorrelation function

Power Spectral Density Estimation

$$S_h(f) = \lim_{T\to\infty} \frac{2}{T} \int_0^T h(t)e^{2\pi i f t}dt \int_0^T h(t')e^{-2\pi i f t'}dt'$$

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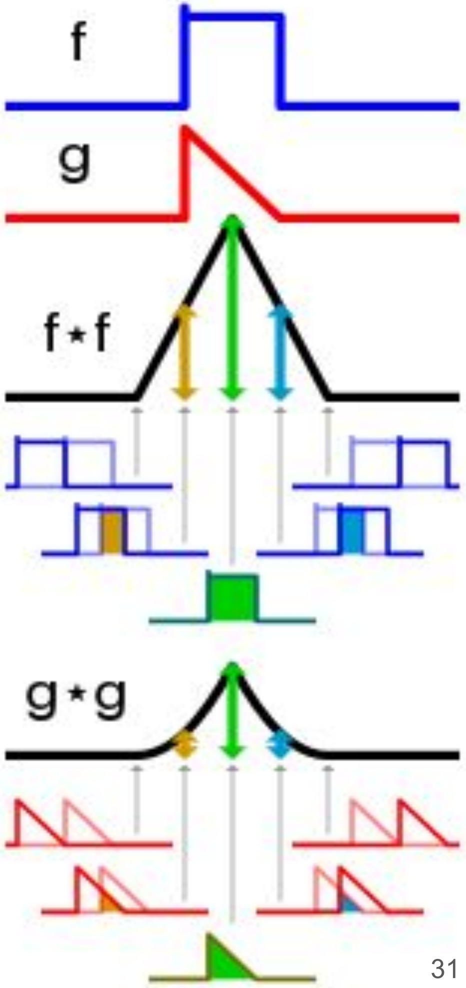
Autocorrelation function



wikipedia

Power Spectral Density Estimation

$$S_h(f) = 2\int_{-\infty}^{\infty} d\tau e^{-2\pi i f\tau} \boxed{\left[\lim_{T\to\infty}\int_0^T h(t')h(t'+\tau)dt'\right]}$$

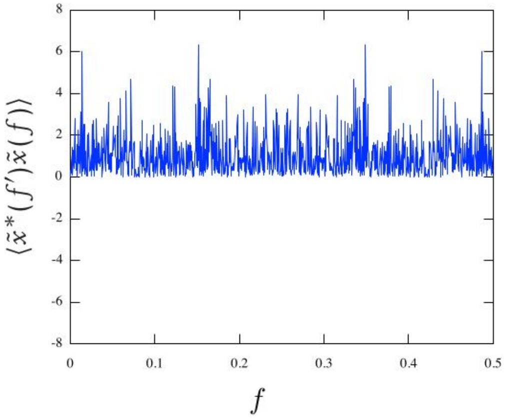
$$S_h(f) = 2\int_{-\infty}^{\infty} \boxed{R(\tau)} e^{-2\pi i f\tau} d\tau$$

$$\langle \tilde{h}^*(f')\tilde{h}(f) \rangle = \boxed{\int_{-\infty}^{\infty} dt' e^{-2\pi i(f-f')t'}} \boxed{\int_{-\infty}^{\infty} d\tau e^{-2\pi i f\tau} \langle x(t')x(t'+\tau)\rangle}$$

$$\boxed{\langle \tilde{h}^*(f')\tilde{h}(f)\rangle = \frac{1}{2} S_h(f)\delta(f-f')}$$

Power spectral density estimation

$$\langle \tilde{h}^*(f')\tilde{h}(f)\rangle = \frac{1}{2}S_h(f)\delta(f-f')$$



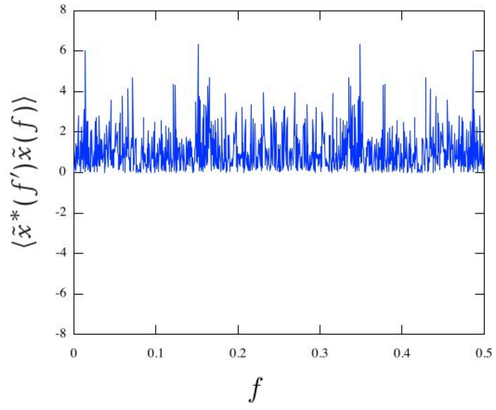
$S_h(f) \longrightarrow S_o$ **(constant)**

$\boxed{\textbf{White noise}}$

Credit : P. Ajith

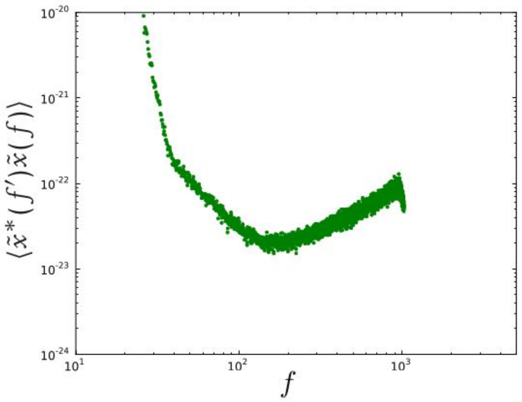
Power spectral density estimation

$$\langle \tilde{h}^*(f')\tilde{h}(f)\rangle = \frac{1}{2}S_h(f)\delta(f-f')$$



$S_h(f) \longrightarrow S_o$ **(constant)**

White noise



$S_h(f) \longrightarrow$ **varies with f**

Coloured noise

Credit : P. Ajith

Points to remember here

- **Assuming wide sense stationary noise**

$$\langle n(t)\rangle = \langle n(t+\tau)\rangle \quad\quad \langle n(t)n(t^{'})\rangle = \langle n(t+\tau)n(t^{'}+\tau)\rangle$$

same mean

same covariance

$$\vec{n} = (n_1, n_2, \ldots n_N)$$

N dim vector

Stationary gaussian noise model

$$\boxed{p(\vec{n}) = \frac{1}{(2\pi)^{N/2}\sqrt{detC}} e^{-\frac{1}{2}\vec{n}^T C^{-1}\vec{n}}}$$

Cov matrix

$$C_{ik} = \langle n_i n_k \rangle$$

$$k = 1, 2, ..N$$

Dominant sources of noise

1. Seismic Noise

- Displacement noise caused by ground motion

LIGO capable of sensing

(1) vibrations from traffic on nearby roads

(2) weather patterns on the other side of the continent

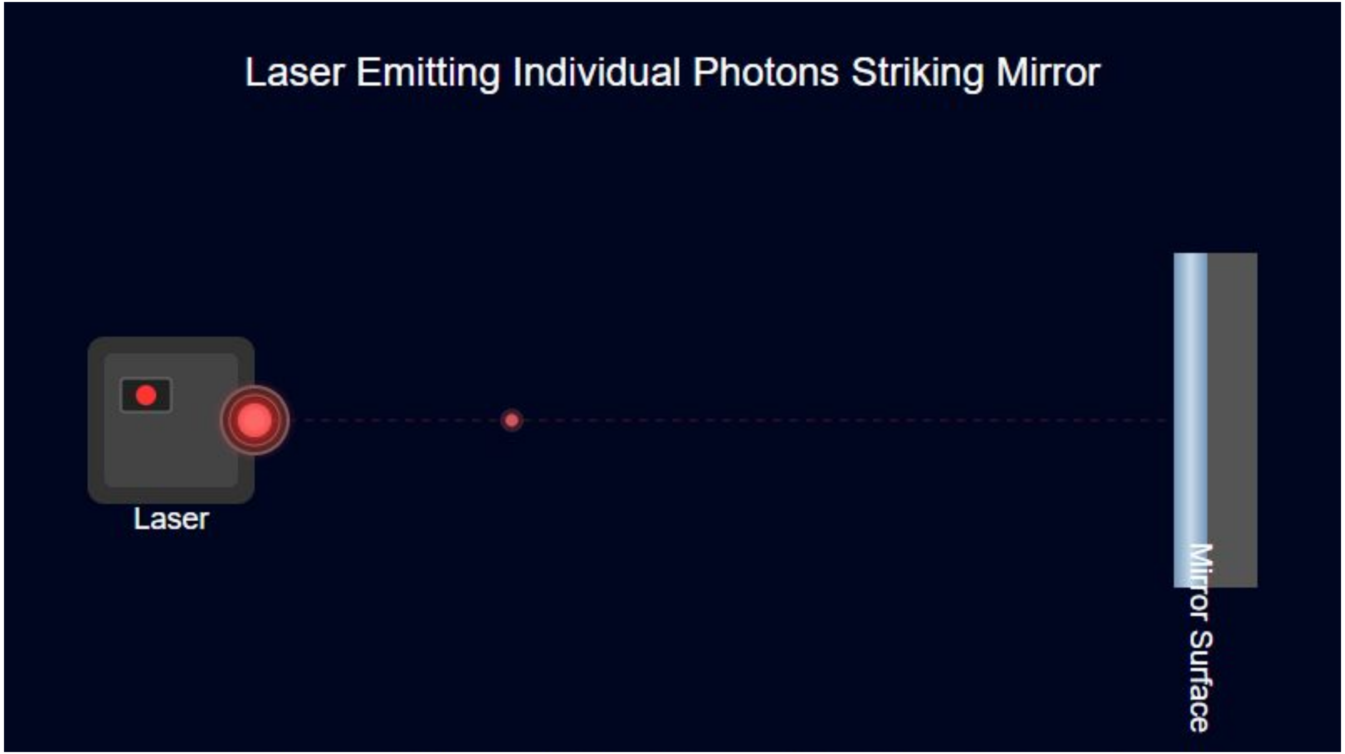
(3) staff driving alongside the detector's arms

(4) the surging waters of the ocean

(5) and of course nearly every significant earthquake on the planet

Shielded from these via various seismic isolation techniques

Classify the noises



Standard Quantum Limit

Shot Noise

laser power

radiation pressure noise

Balance out Shot noise and Radiation noise (Standard quantum limit)

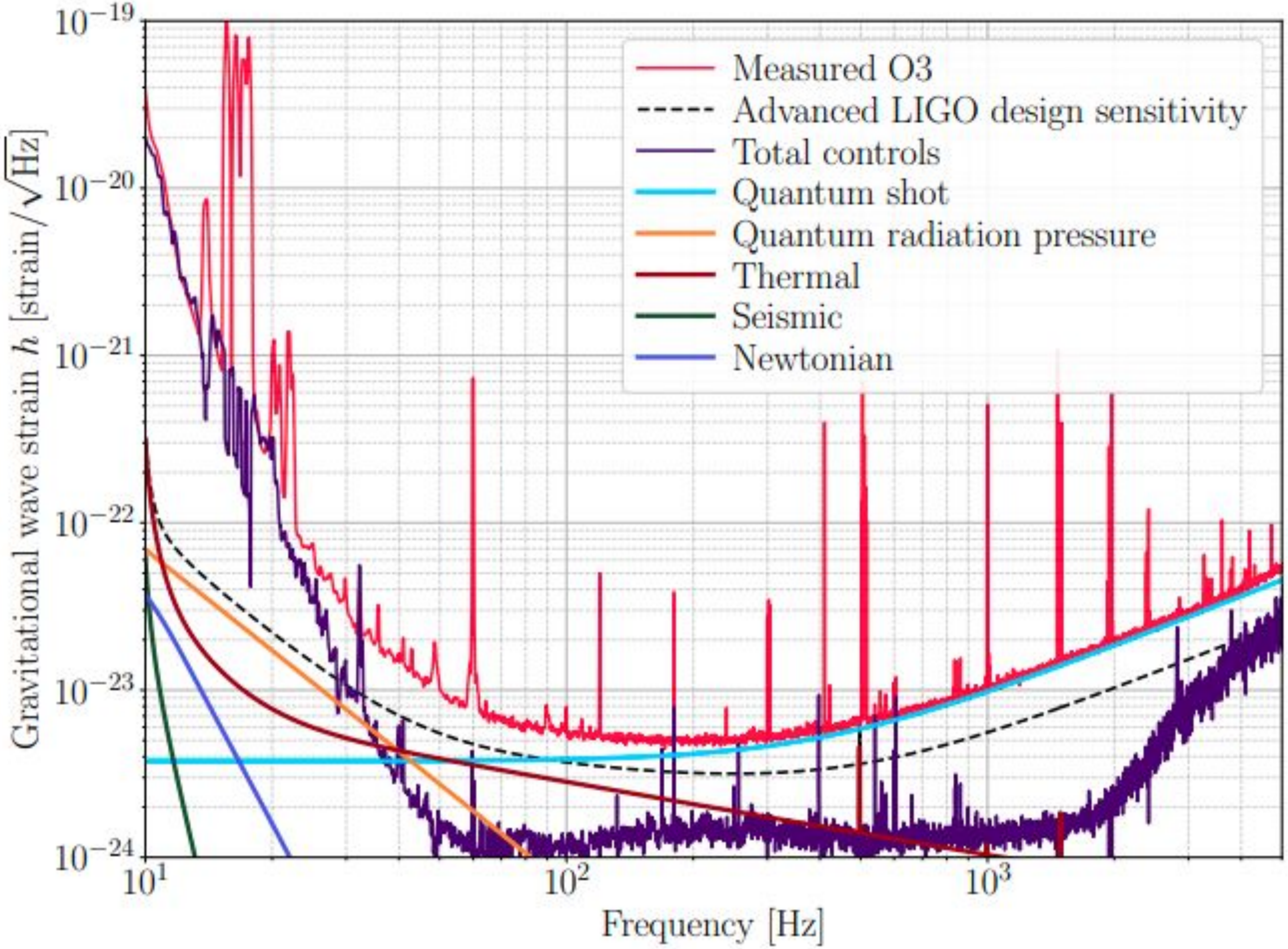
Other sources of noise

1. **Thermal Noise** **-** Arises from thermal fluctuations in both mirrors and suspensions

2. **Suspension Thermal Noise** **-** Motion induced by thermal fluctuations and vibrations of suspension fibers

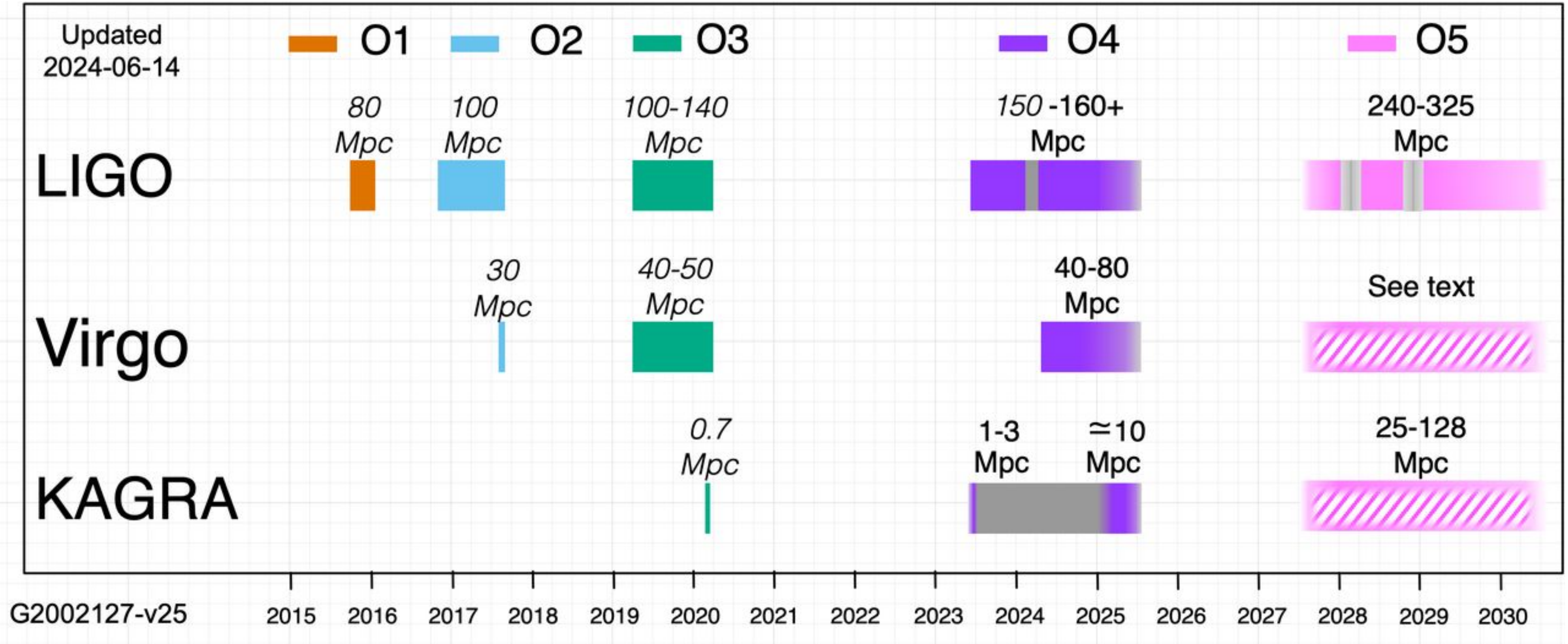
3. **Test-Mass Thermal Noise** - Expansion/contraction of mirror material and temperature-induced changes in refractive index

Thermal noise typically dominates in the mid-frequency range (~50–300 Hz) and strongly depends on the material properties.



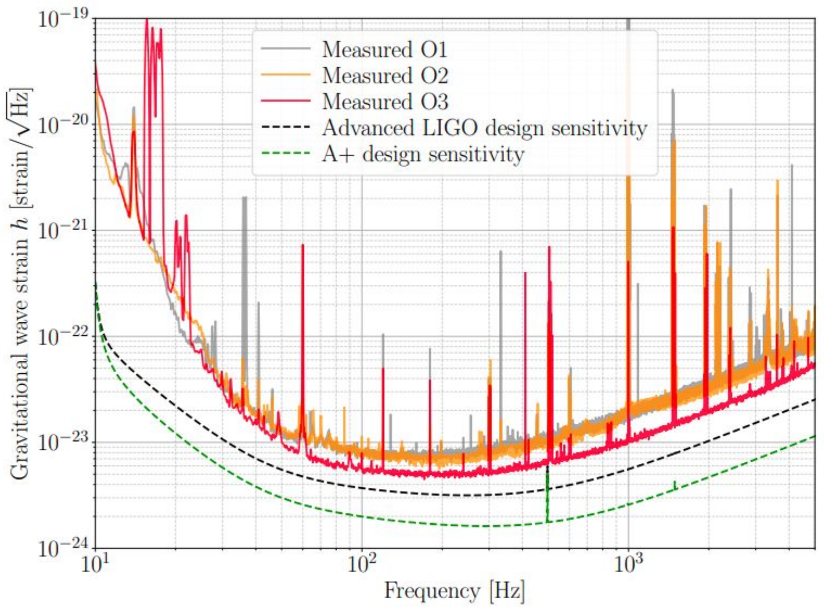
arXiv:2202.00847v1

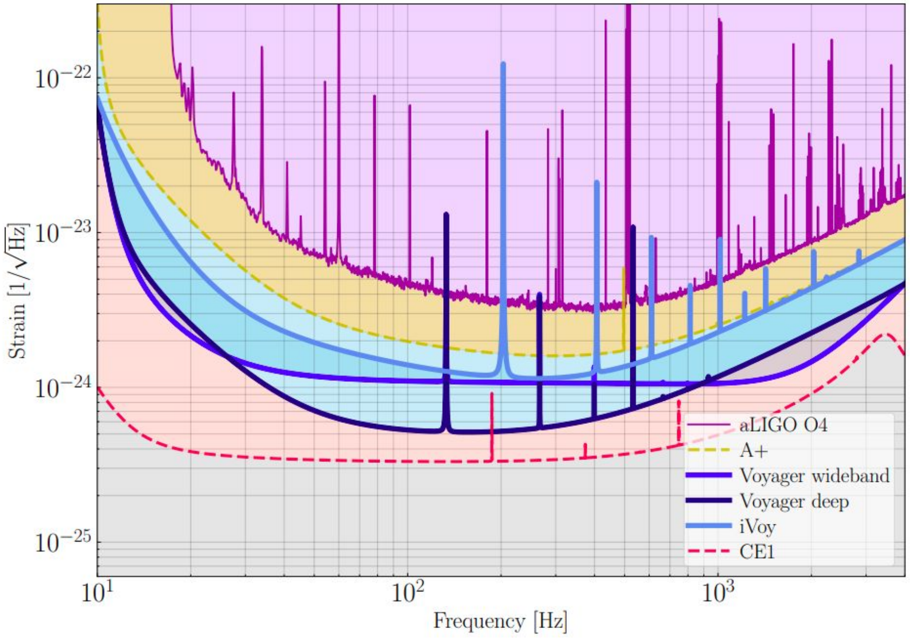
Comparison of LIGO sensitivity curves in various observing runs and future prospects



www.ligo.caltech.edu/page/observing-plans

Comparison of LIGO sensitivity curves in various observing runs and future prospects





arXiv:2202.00847v1

Voyager white paper

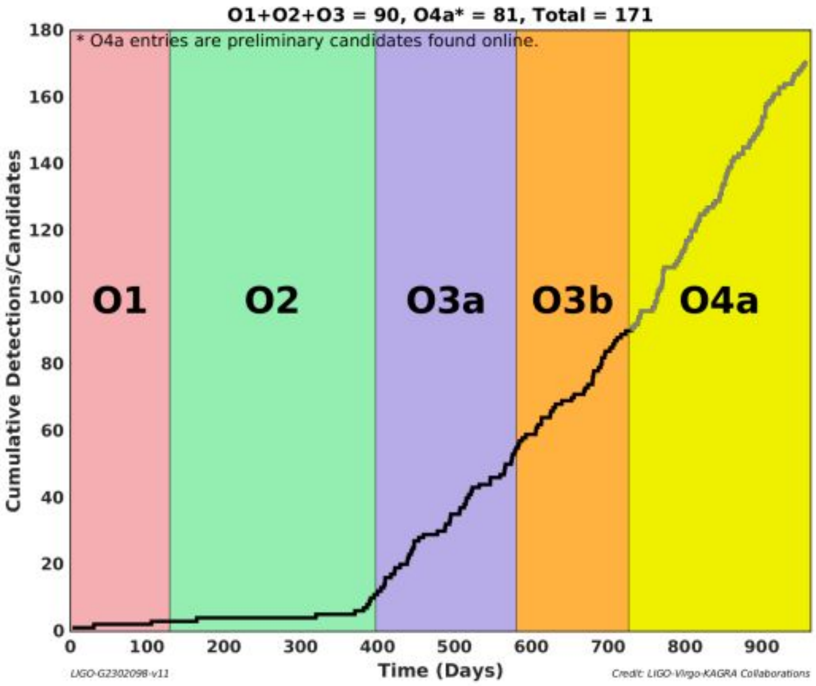
Gravitational Wave Transient Catalogue (GWTC)

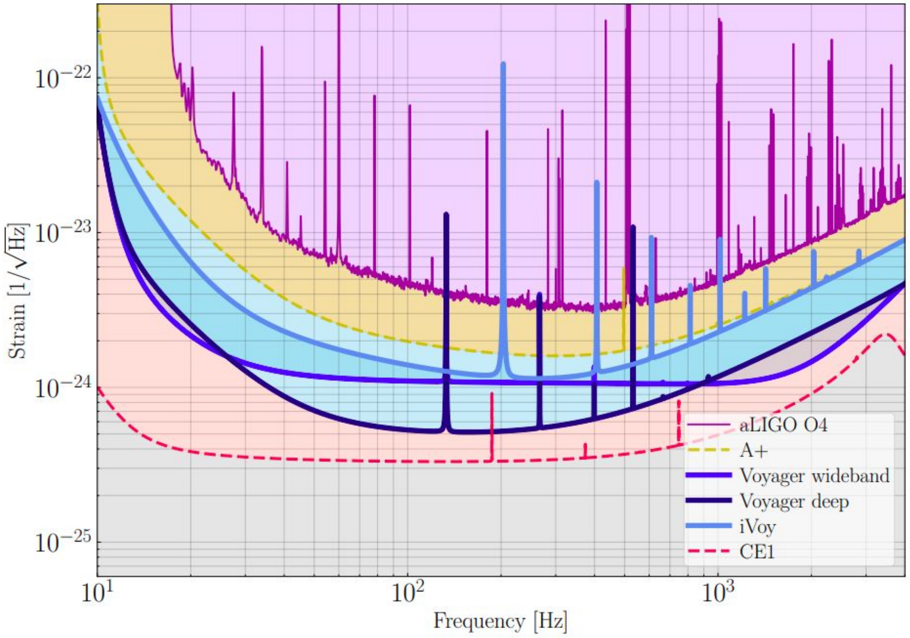
Run	Dates	Duration (months)	Detections
O1	September 18, 2015 to January 12, 2016	3	3
O2	November 30, 2016 to August 25, 2017	9	8
O3	April 1, 2019 to March 26, 2020	11	79
			Candidates
O4	May 24, 2023 to March 19, 2025	23	200

(more on this when we talk about open data)

https://www.ligo.caltech.edu/news/ligo20250320

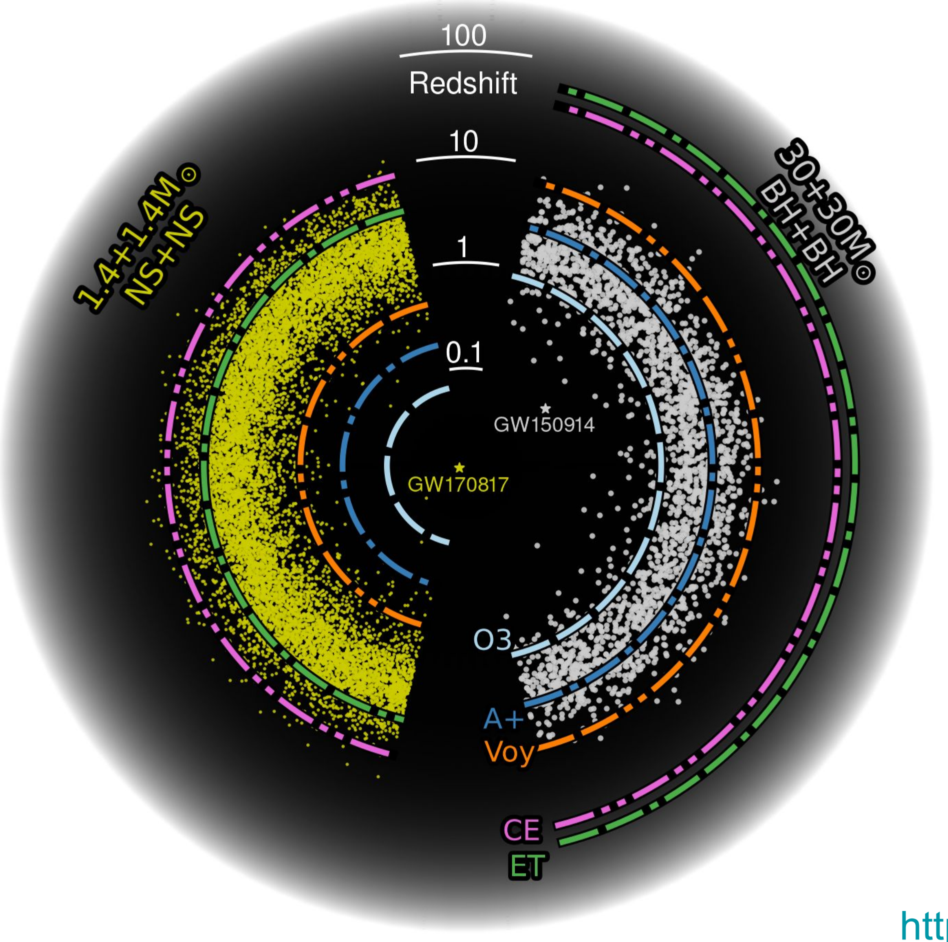
Comparison of sensitivity curves in various observing runs and future prospects

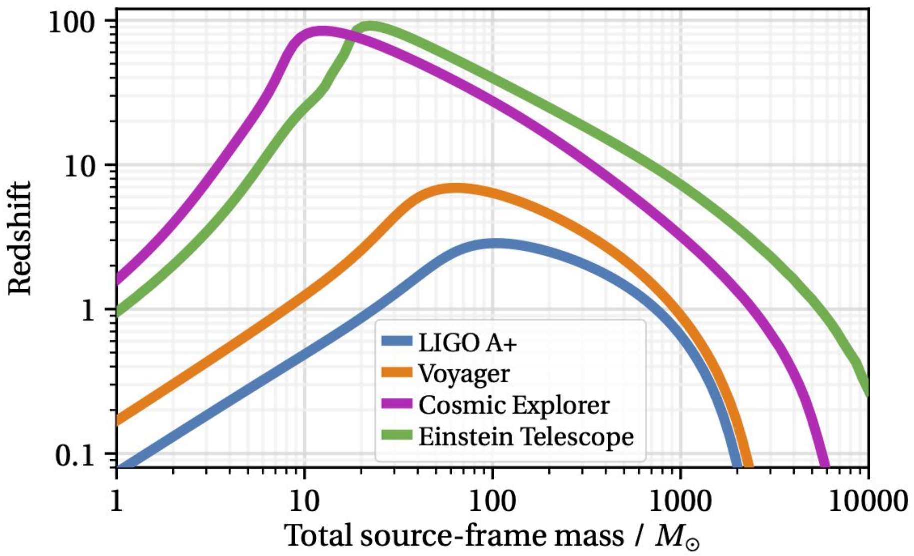




https://dcc.ligo.org/LIGO-G2302098-v15/public

Voyager white paper





https://cosmicexplorer.org/sensitivity.html

Non - stationarity

Stationary process has statistical properties (like mean, variance, power spectrum) - **no change with time**.

Non-stationarity means:

- **Noise characteristics evolve over time - Difficult to model the noise** with a single PSD over the whole data stretch
- Time-varying noise mask / mimic GW signals, often handled by using **short data segments**

Detector more sensitive at night time than day time due to reduced environmental disturbance

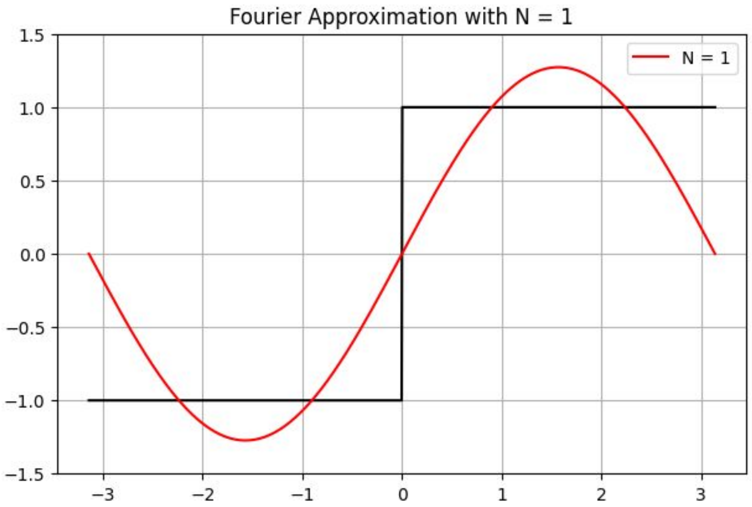
Non - gaussianity

Gaussian noise follows normal distribution — fully characterized by its mean and variance, and extreme deviations rare

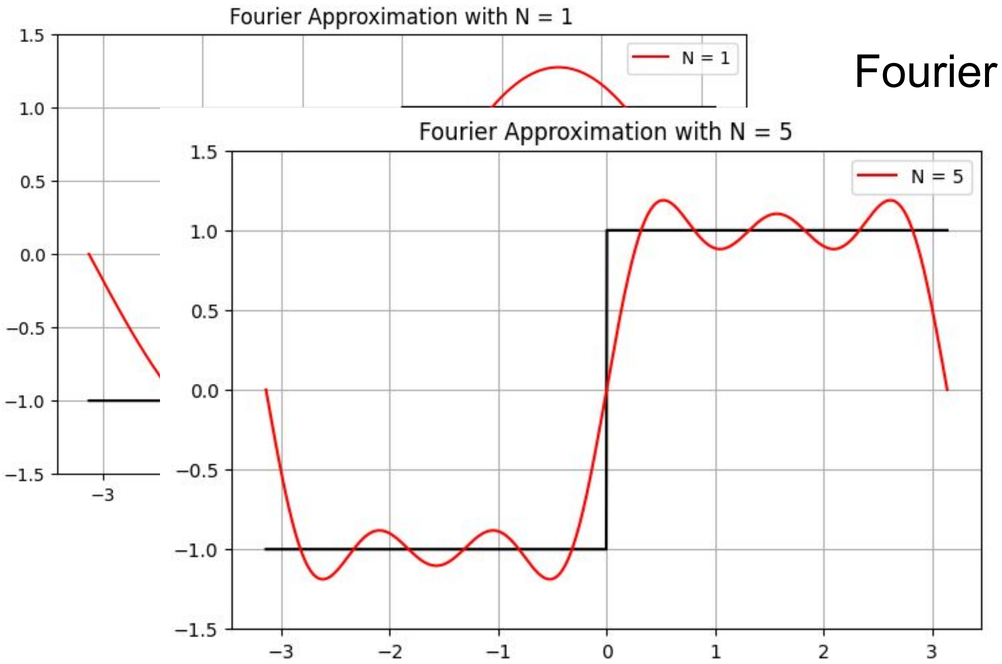
Non-Gaussianity means:

- The noise contains "glitches" — short-duration transients with large amplitudes
- Noise probability distribution has heavy tails — extreme outliers are more frequent than expected
- Glitches can be mistaken for short GW signals (e.g., mergers)

Analysis assumes gaussian noise - non-gaussian noise difficult to implement in likelihood implementation (more in lecture 5)

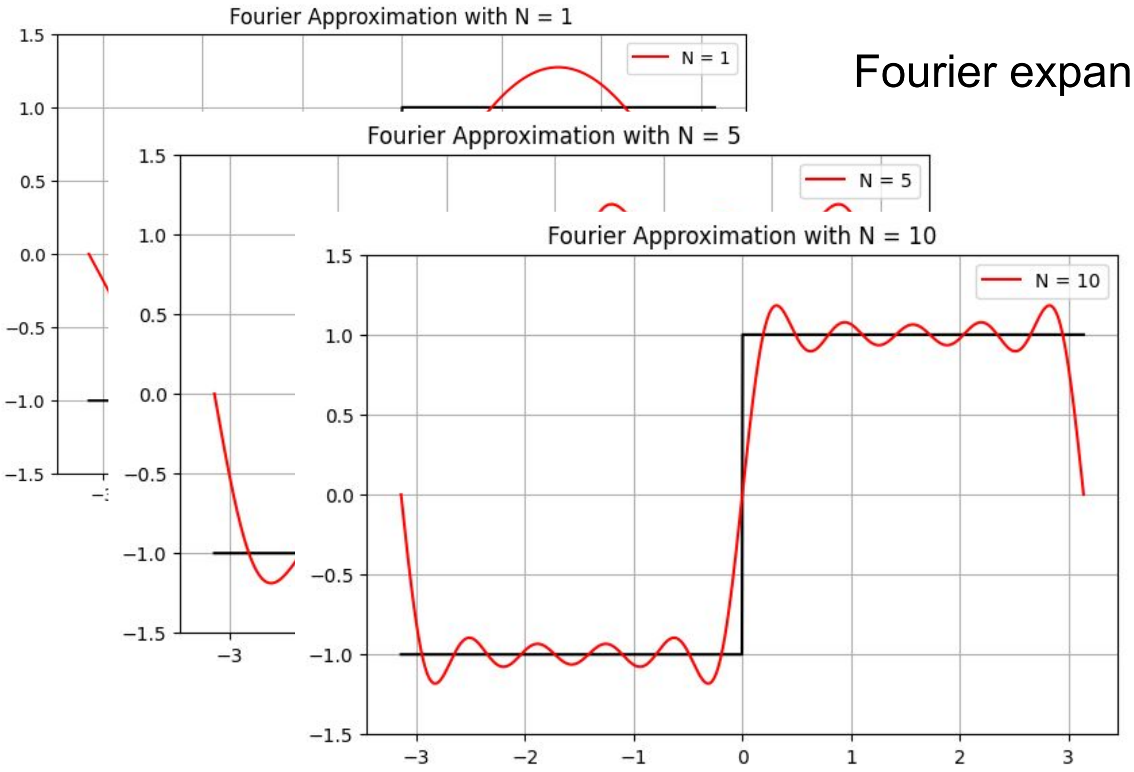


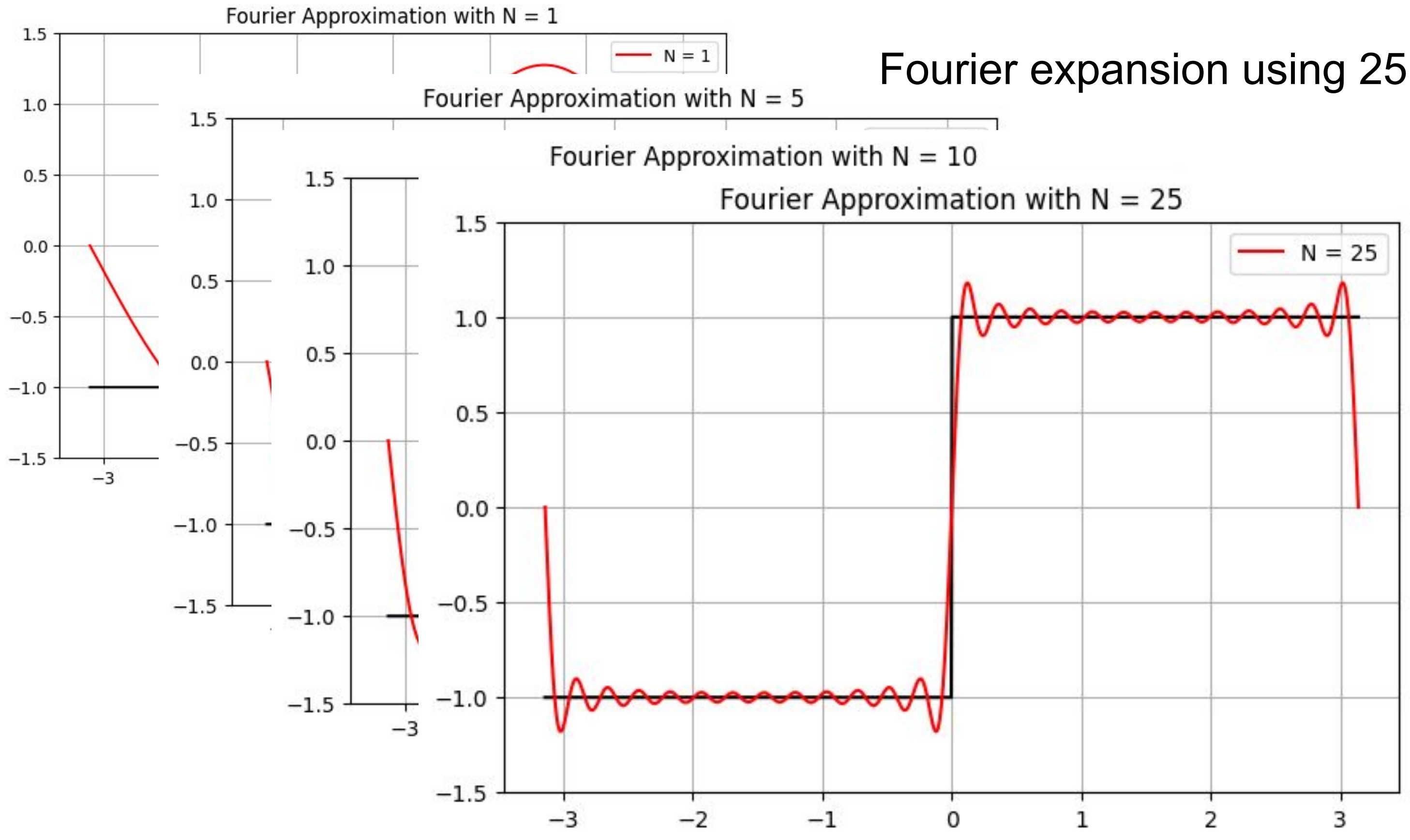
Fourier expansion using a single term in the series



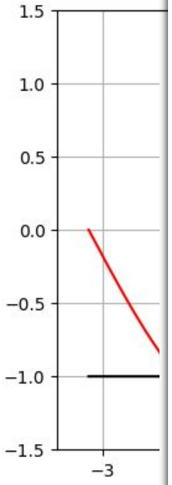
Fourier expansion using 5 terms in the series

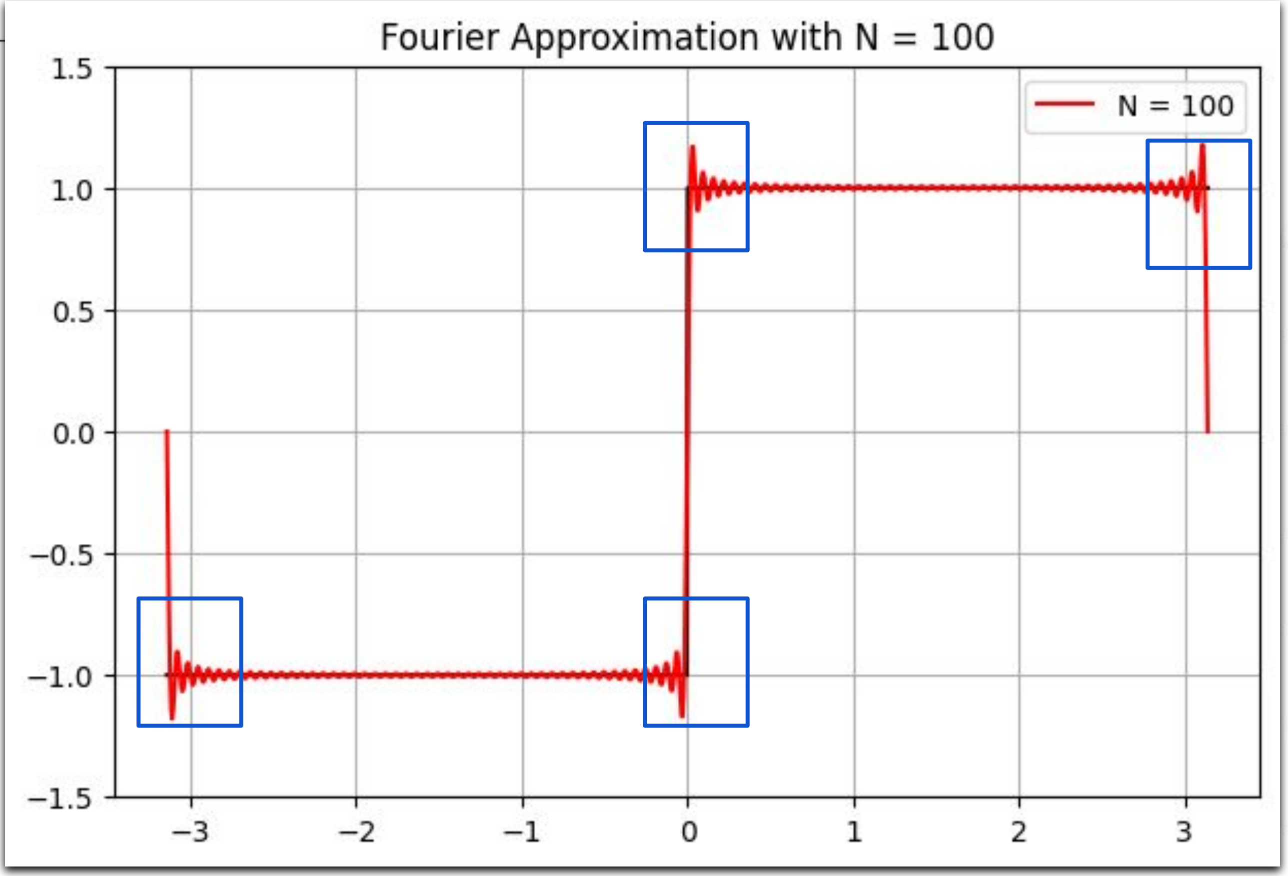
Fourier expansion using 10 terms in the series





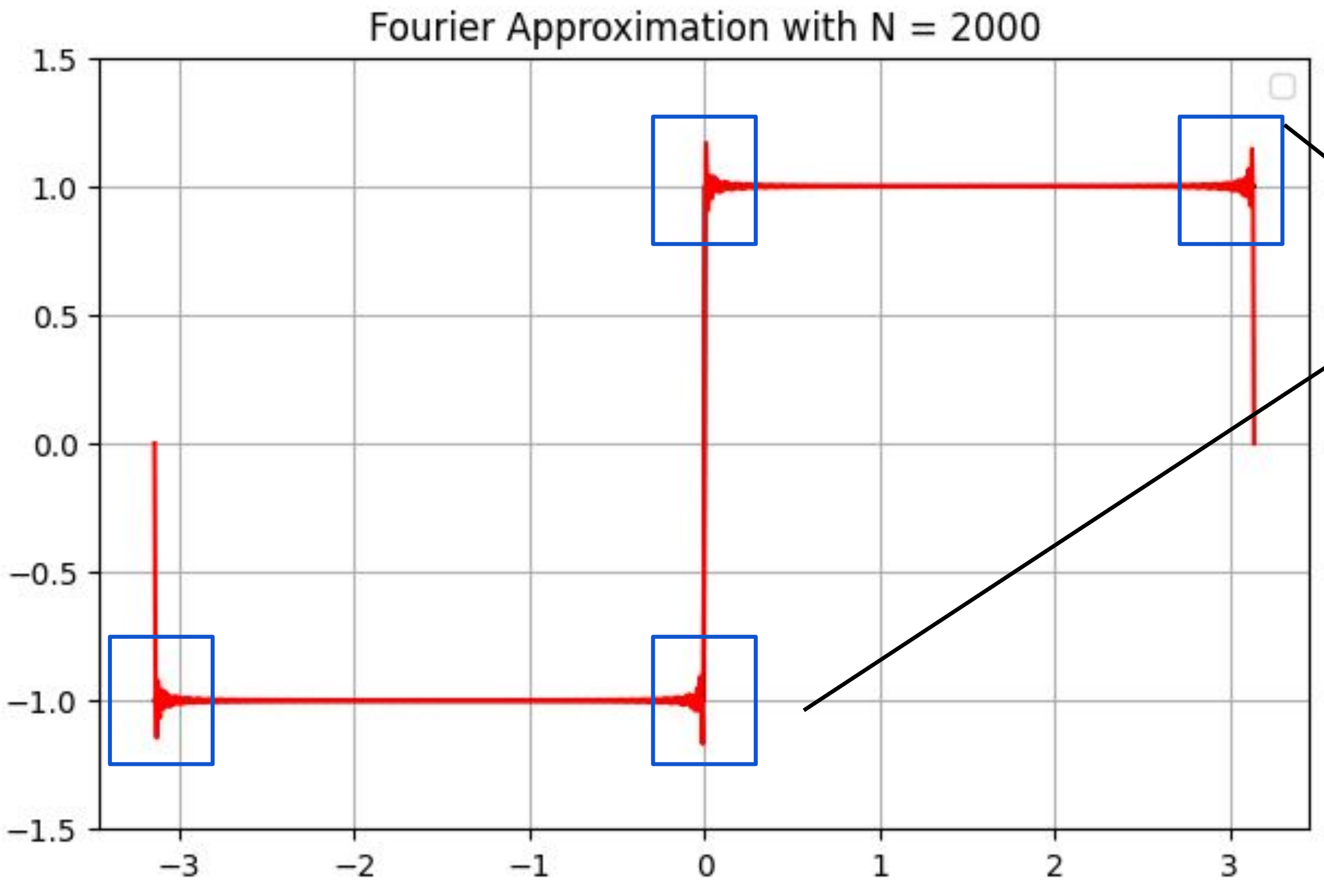
Fourier expansion using 25 terms in the series





Fourier expansion using 100 terms in the series

Gibbs Phenomenon

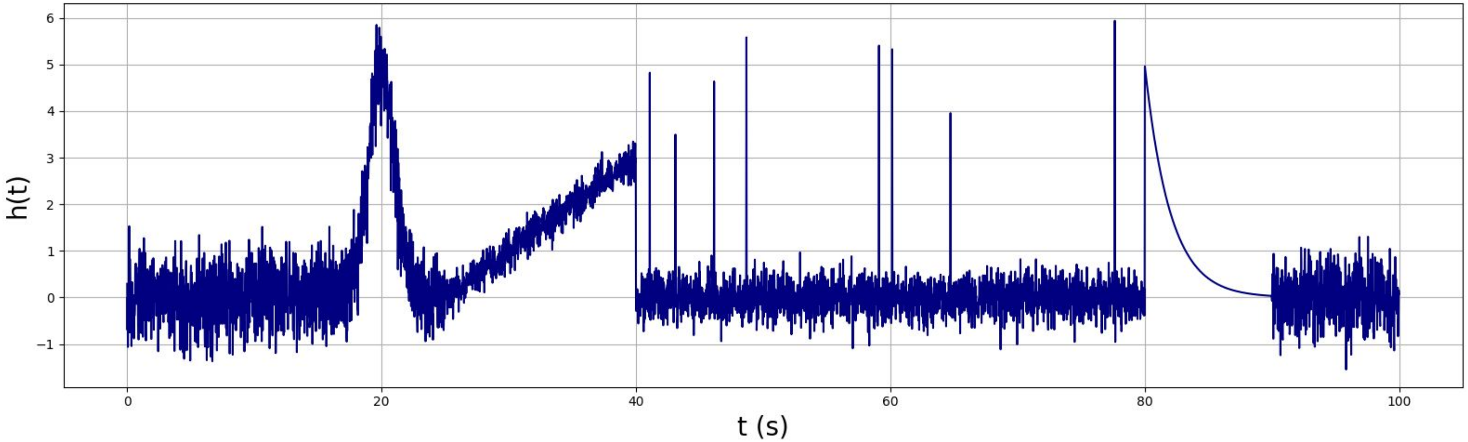


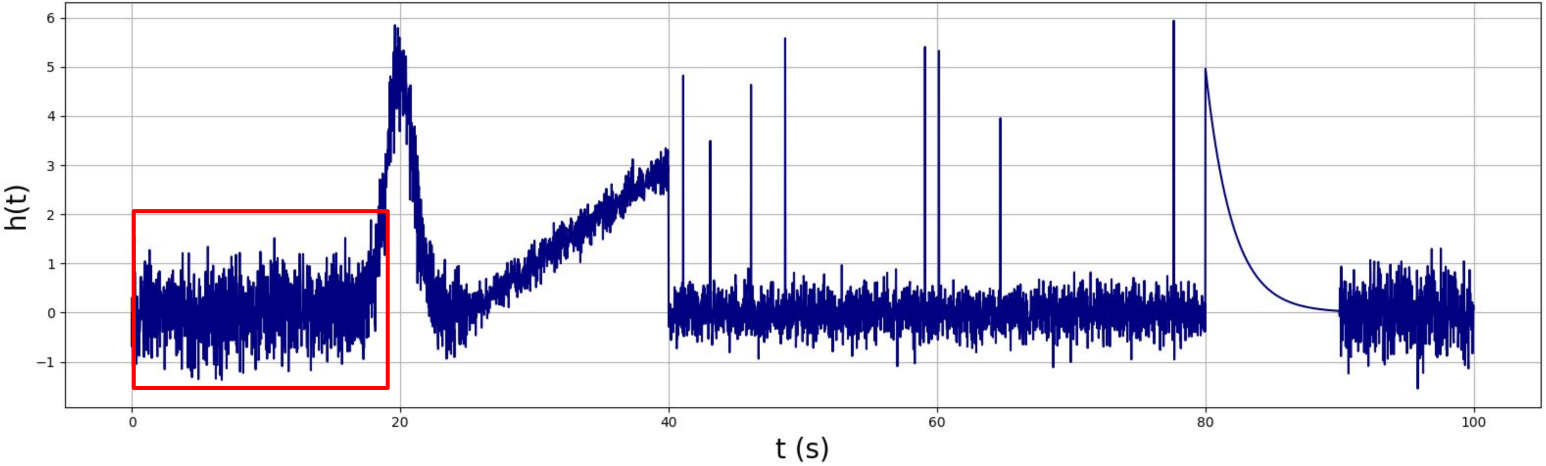
Gibbs phenomenon

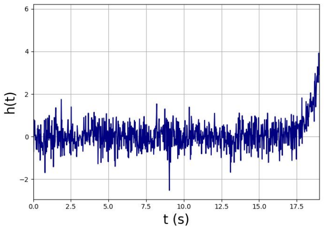
Need to manipulate the discontinuities

Segmenting data reducing discontinuities

PSD estimation by Welch Method

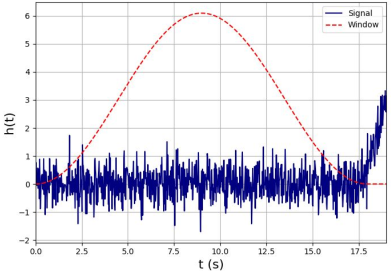




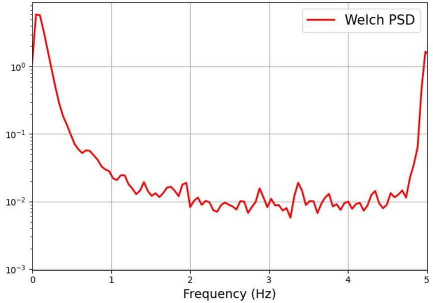


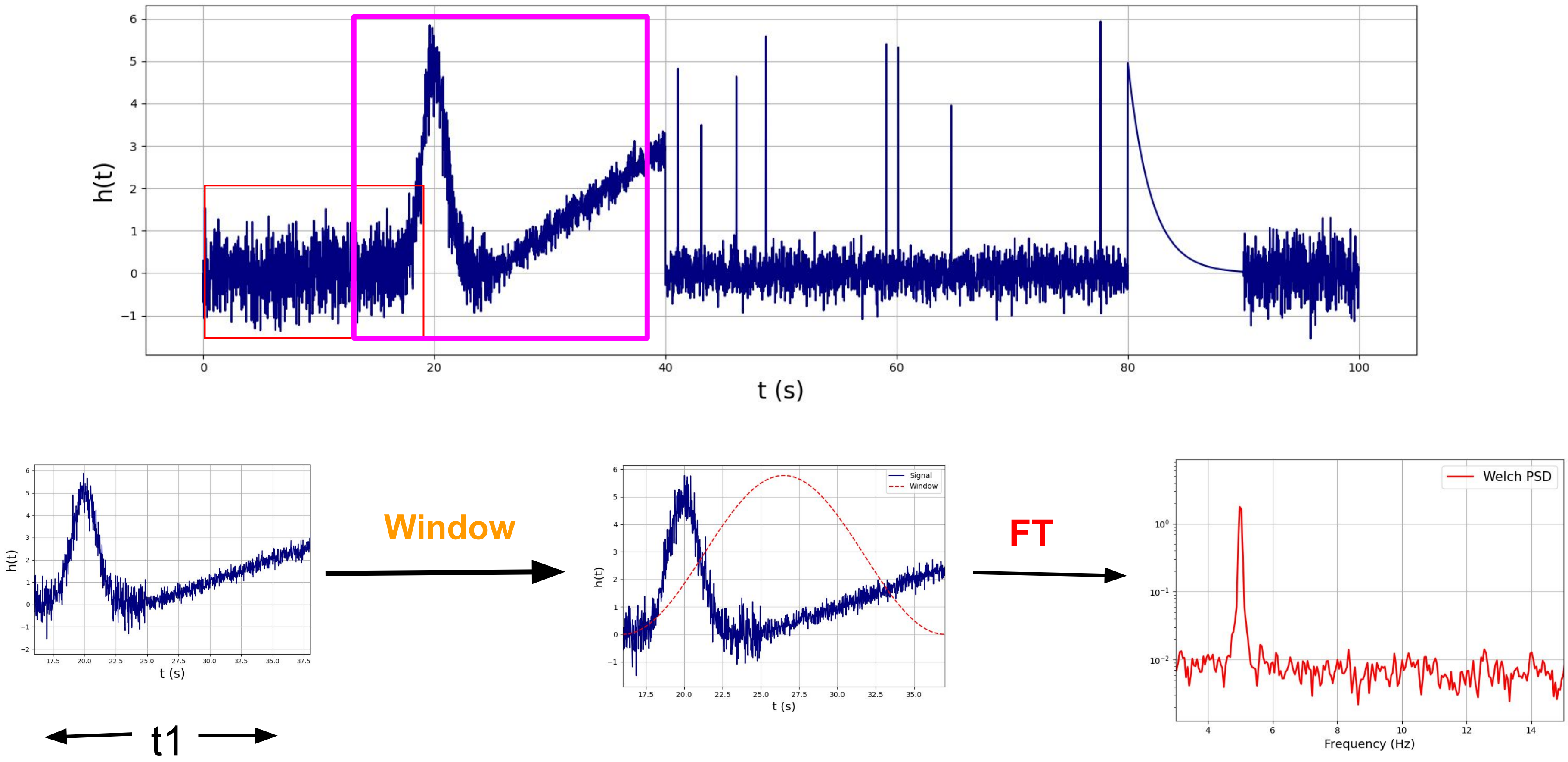
t1

Window



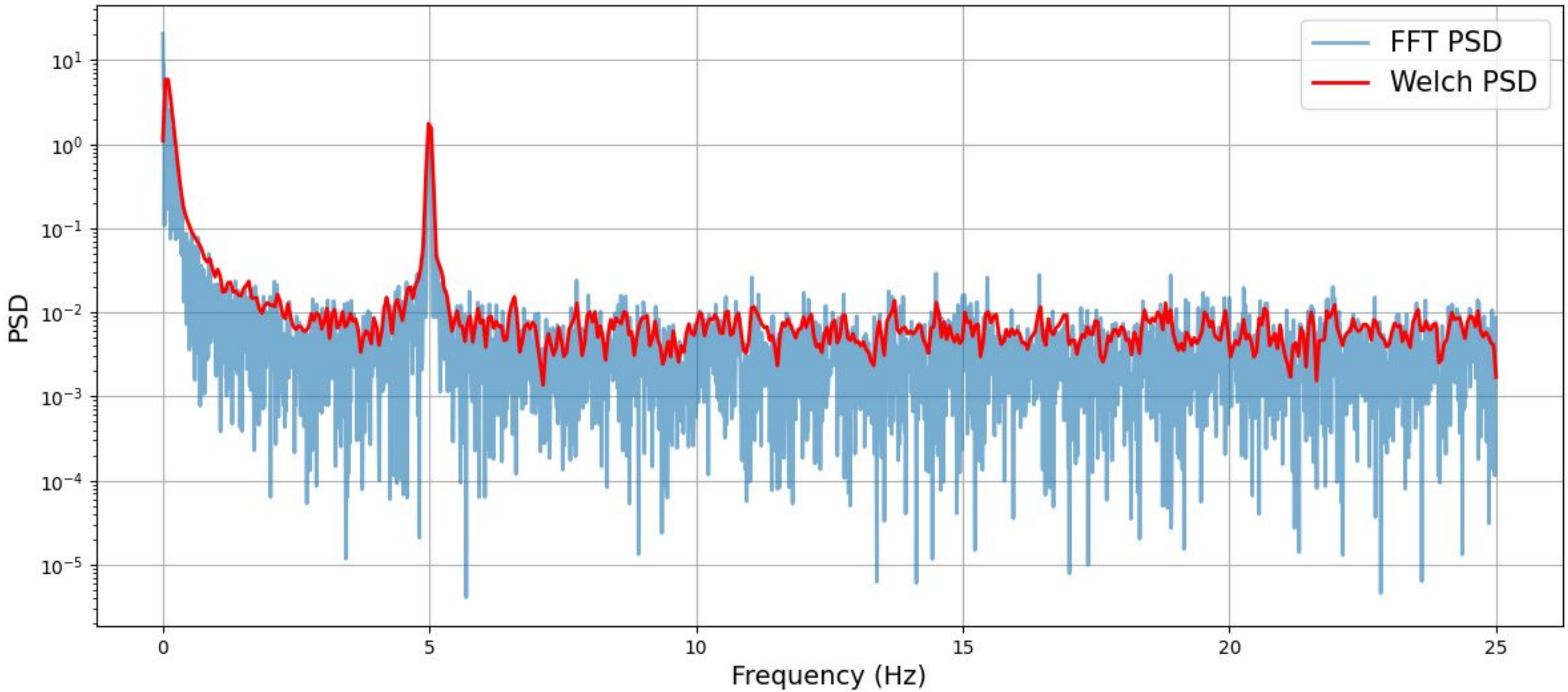
FT





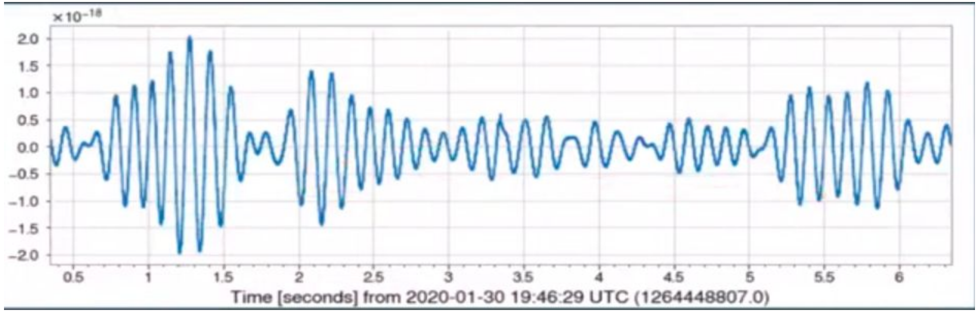
h(t)
t (s)
Window
Signal
Window
FT
Welch PSD
Frequency (Hz)
t1

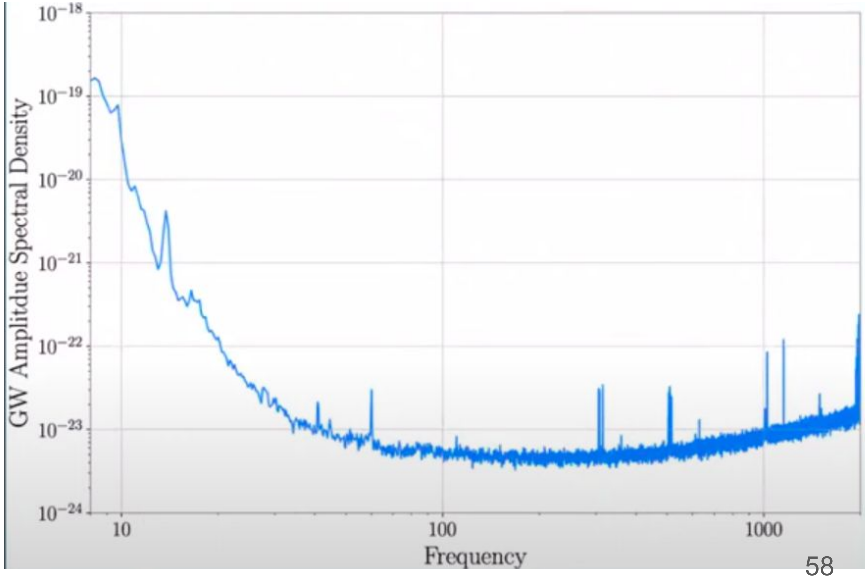
Comparison of PSD via FFT and Welch



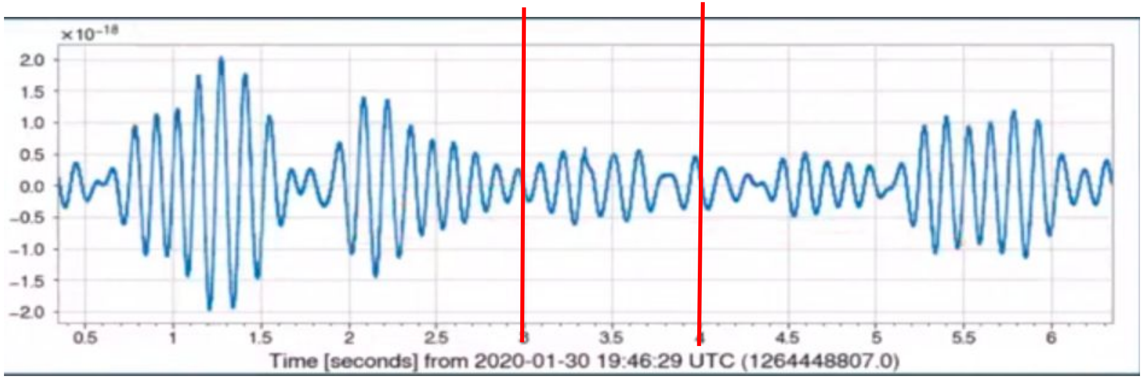
Whitening the data

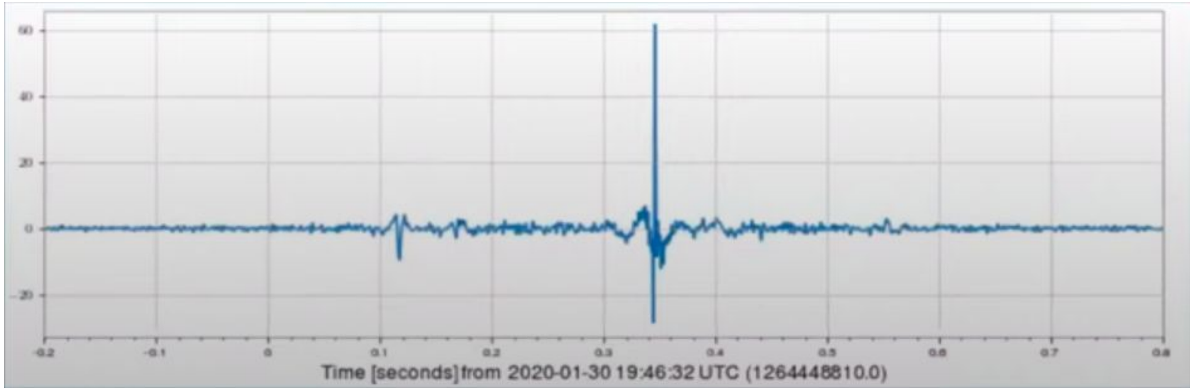
- Transforming strain data to freq domain allows us to average detector sensitivity for each freq bin (PSD)
- Having ASD allows us to whiten the data, **in other words scale the data**
- E.g., - detector less sensitive at lower freq (< 20Hz), so the data at low freqs should be less important than that at medium freqs





Whitening the data





Spectrogram and Q-transform

- FFT and time series data represent amplitude variation only as a function of time and frequency

Spectrograms and Q-transforms

↓

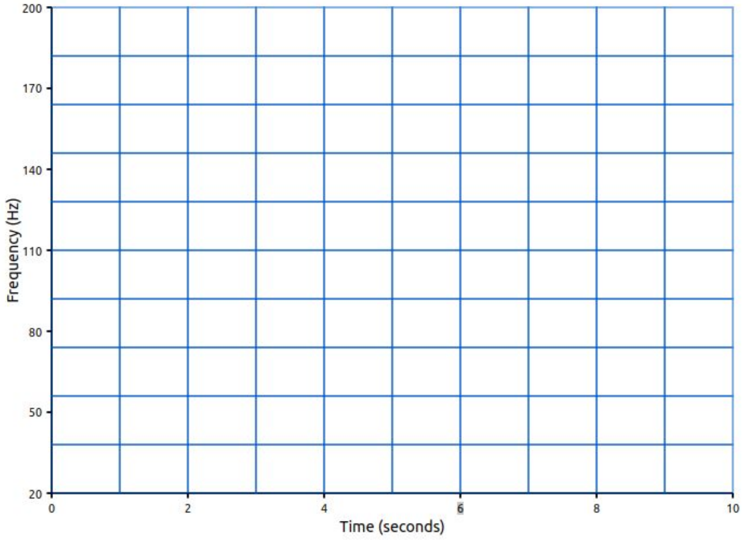
time-frequency analysis methods that represent how signal energy is distributed across

↓

both time and frequency domains

Spectrogram and Q-transform

- **Spectrogram** uses **uniform time windows** across all frequencies regardless of the frequency being analyzed

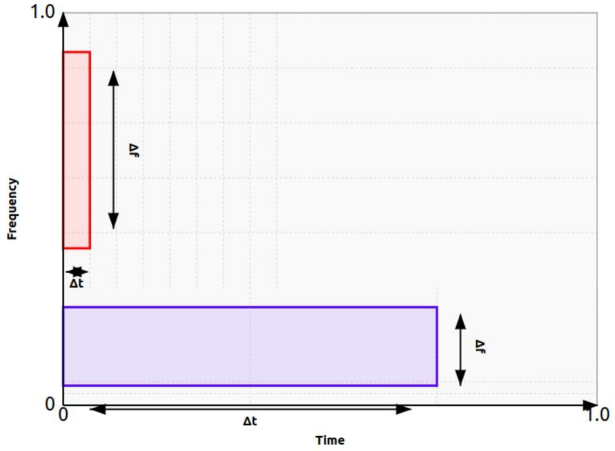


Uniform tiling

Spectrogram and Q-transform

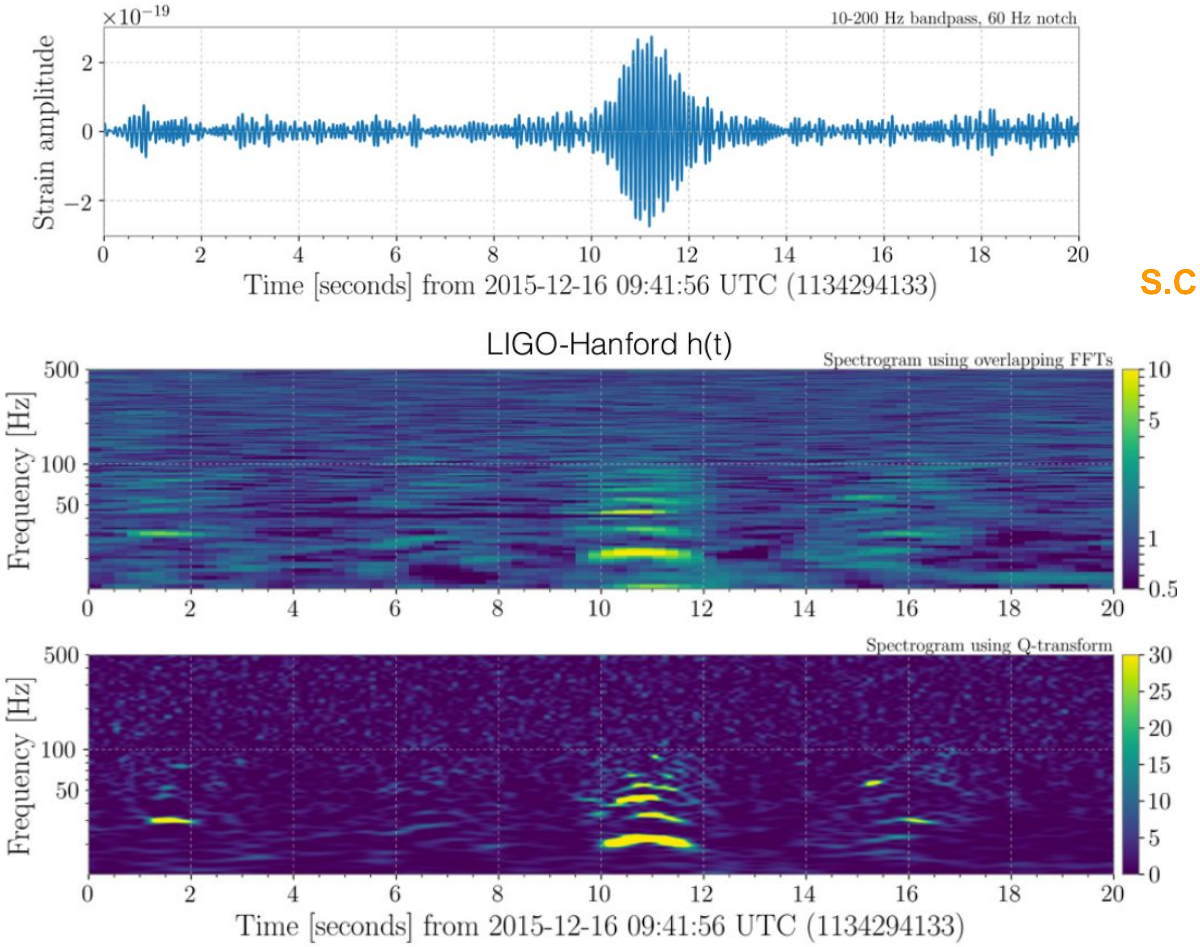
- **Q transform** uses **variable-sized time windows** that scale with frequency

lower frequencies - longer windows → better frequency resolution and
higher frequencies - shorter windows → better time resolution



Logarithmic tilling

Time - frequency spectrum



S.Chaterji et.al. 2010

Glitches

- Particularly troublesome type of noise are **glitches**: bursts of noise that complicate the analysis of gravitational-wave data

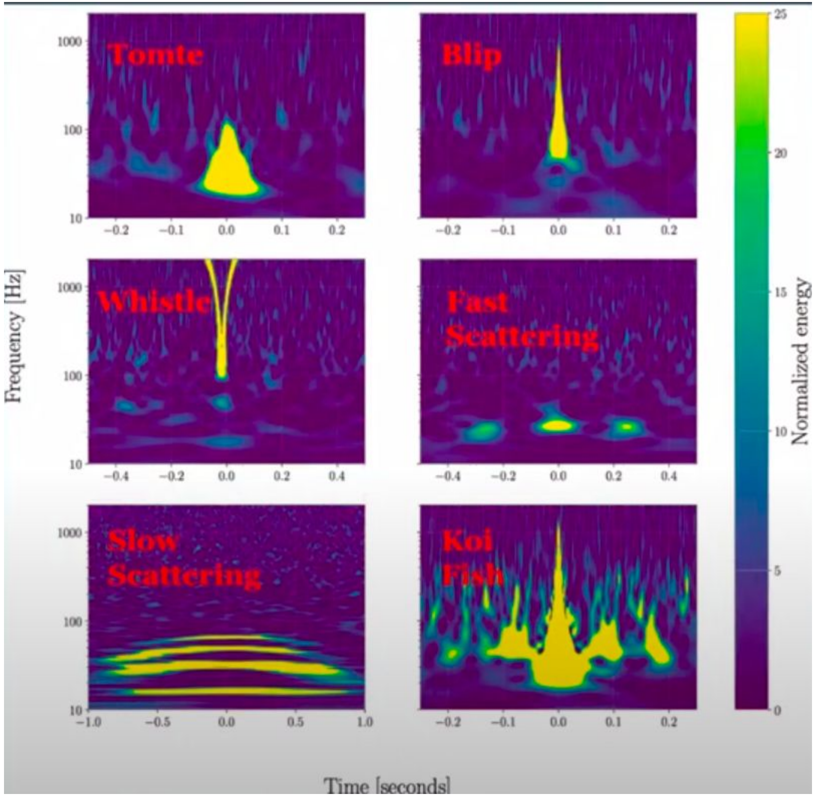
- Origin of glitches can be natural, human made e.t.c.

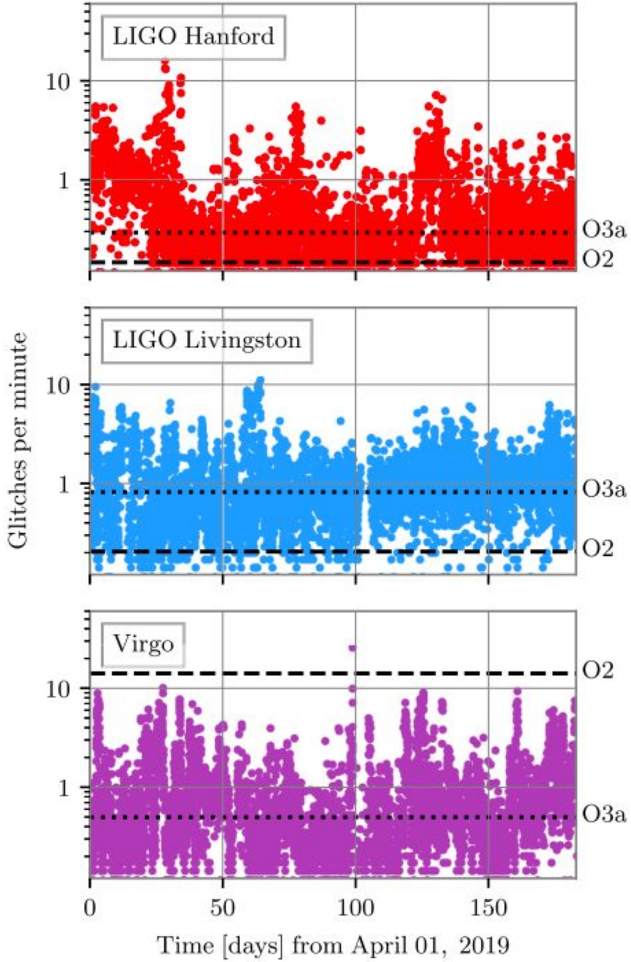
- Sometimes glitches look like actual gw signals (**e.g. blip**)

- Glitches are detected and analysed using **Omicron, GravitySpy, Q-transform, Hveto** e.t.c.

- Glitch rate varies over time with every observing run

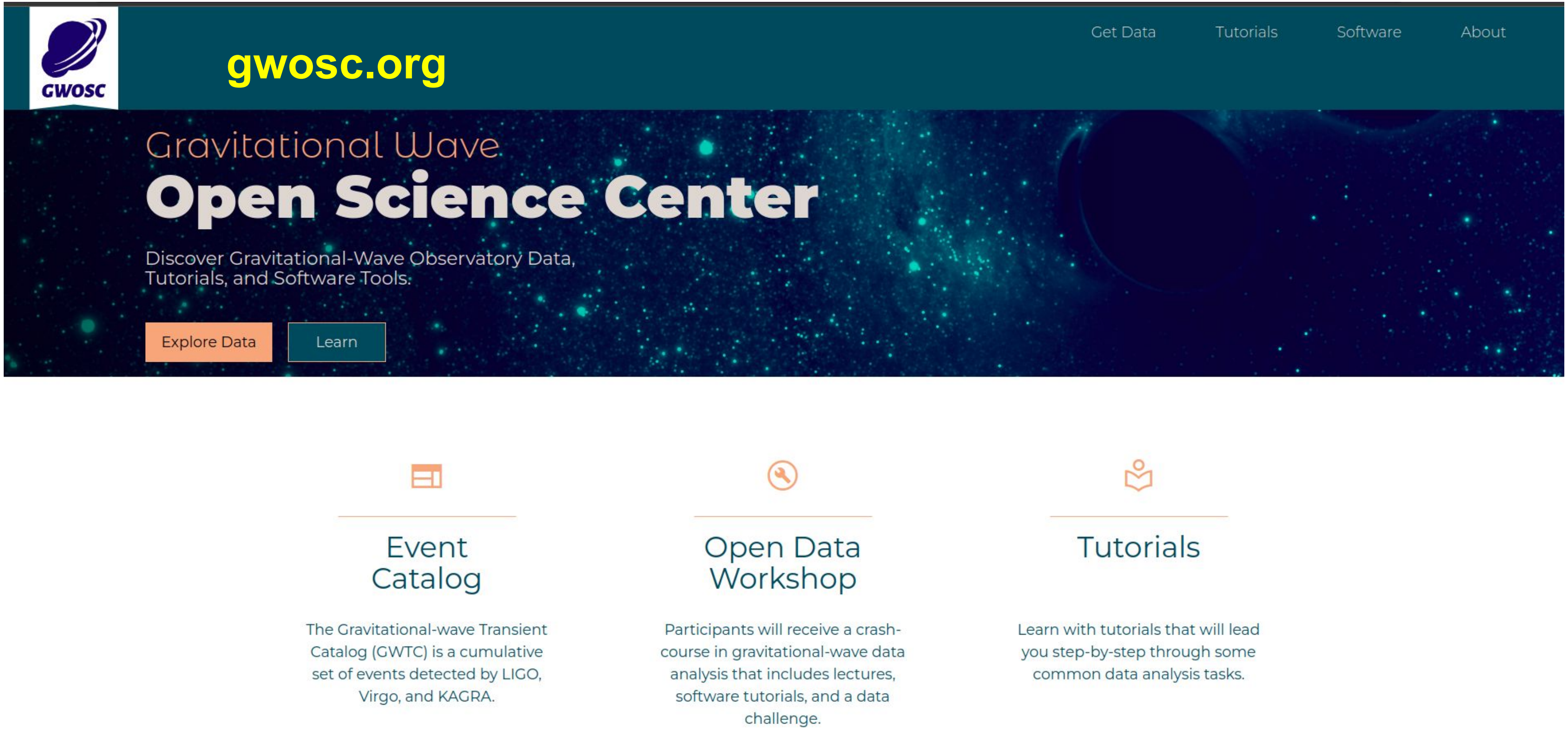
Glitches



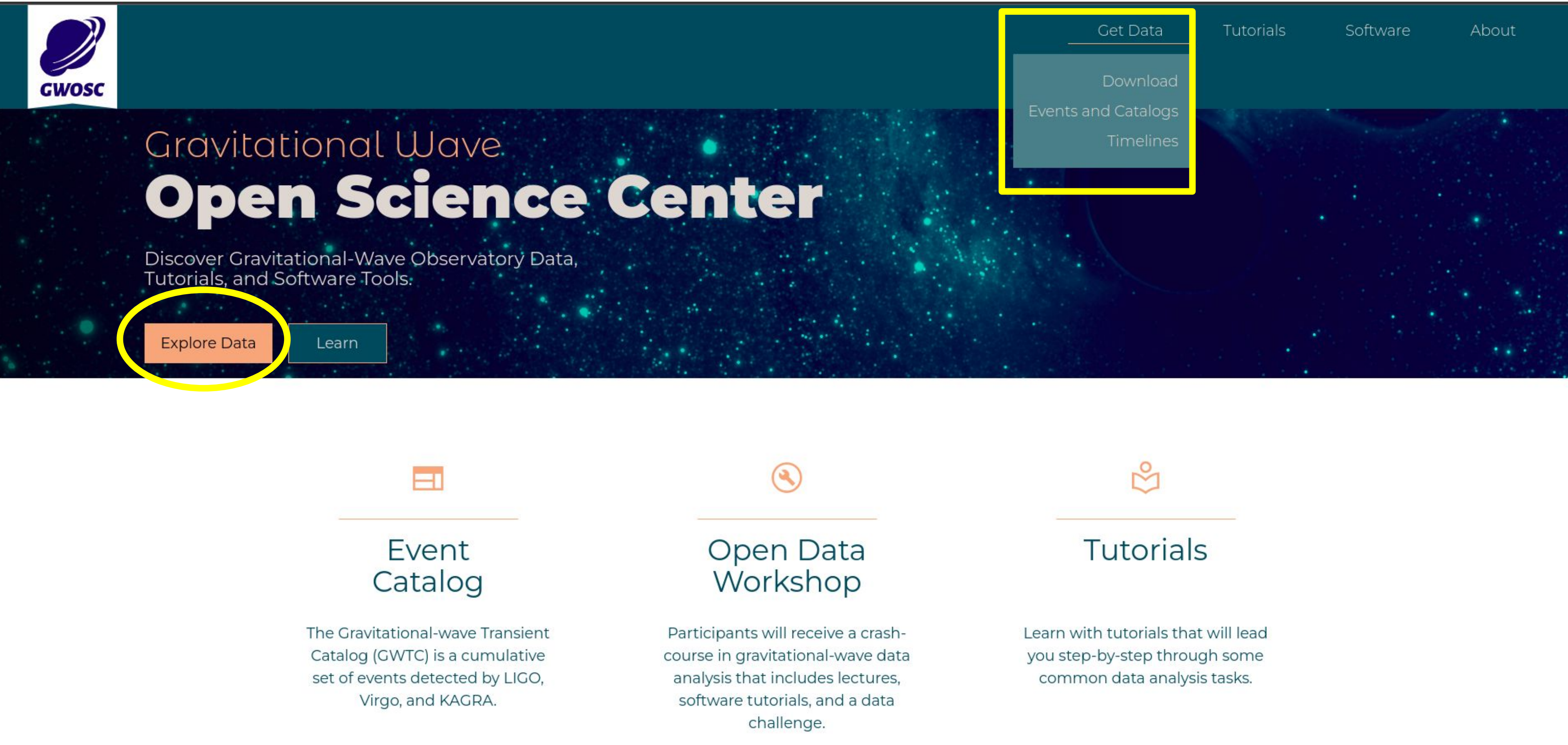


GravitySpy.org, Ligo-Virgo(2021)

Introduction to GW Open Data Resources



- Releases **gravitational wave data** to the broader scientific community and public
- Provide **event catalogs** with strain data and other details
- Provides **documentation and tools** to understand and utilise the data


GWOSC
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Tutorials
Software
About
Download
Events and Catalogs
Timelines
Gravitational Wave
Open Science Center
Discover Gravitational-Wave Observatory Data, Tutorials, and Software Tools.
Explore Data
Learn
Event Catalog
The Gravitational-wave Transient Catalog (GWTC) is a cumulative set of events detected by LIGO, Virgo, and KAGRA.
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Observatory Data Sets

Please Read This First!
Click for data usage notes

The LIGO Laboratory's Data Management Plan describes the scope and timing of LIGO data releases.

Events and Catalogs

Event Portal | Community Catalogs

Large Data Sets

OSDF Docs

For users of computing clusters or if accessing large amounts of data, OSDF is the preferred method to access public data.

CVMFS Docs deprecated: usage will be dismissed starting from August 2025 and replaced by OSDF

GEO Data around FRBs

Documents

Time Range: April 28, 2020 through Dec 2, 2022

Detectors: GEO600 (Select times only)

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GW170814 Auxiliary Data Release

Auxiliary Data

Time Range: 3 hours around event GW170814 (August 14, 2017)

Detectors: H1 and L1

Description: Around 1,000 channels that monitor the LIGO instruments and surrounding enviornment.

O2 Data Release

4 kHz Data | 16 kHz Data | Documents | Timeline

O2 Time Range: November 30, 2016 through August 25, 2017

Detectors: H1, L1 and V1

O1 Data Release

4 kHz Data | 16 kHz Data | Documents | Timeline

O1 Time Range: September 12, 2015 through January 19, 2016

Detectors: H1 and L1

S6 Data Release

Data | Documents | Timeline

S6 Time Range: July 7, 2009 through October 20, 2010

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Detectors: H1 and L1

S6 Data Release

Data | Documents | Timeline

S6 Time Range: July 7, 2009 through October 20, 2010

Entire data for that given run stored in what is called "Bulk Data"

Archive for O3b_4KHZ_R1 dataset

Details

Each data file corresponds to 4096 seconds of GPS time, and may contain up to half a GB. The file may be downloaded in either HDF5 or Frame

For documentation, see the tutorials.

O3b_4KHZ_R1 start GPS: 1256655618, UTC: 2019-11-01T15:00:00

O3b_4KHZ_R1 end GPS: 1269363618, UTC: 2020-03-27T17:00:00

Choose your gravitational wave detector:

H1 L1 V1

Choose the start and end time of the data that you want.

Start Time

UTC 2019-11-01T15:00:00 GPS 1256655618 OK

Choose either Universal time (ISO8601) or GPS. Change either side and the other responds immediately.

End Time

UTC 2020-03-27T17:00:00 GPS 1269363618 OK

Choose either Universal time (ISO8601) or GPS. Change either side and the other responds immediately.

Choose your output format:

- Time series data in HDF5 and Frame files
- Time series data in HDF5 and Frame files, with data quality guide
- Includes statistics of each file: min/max, band-limited RMS, etc.
- JSON formatted table of files and data quality

Continue

Archive

Dataset: O3b_4KHZ_R1

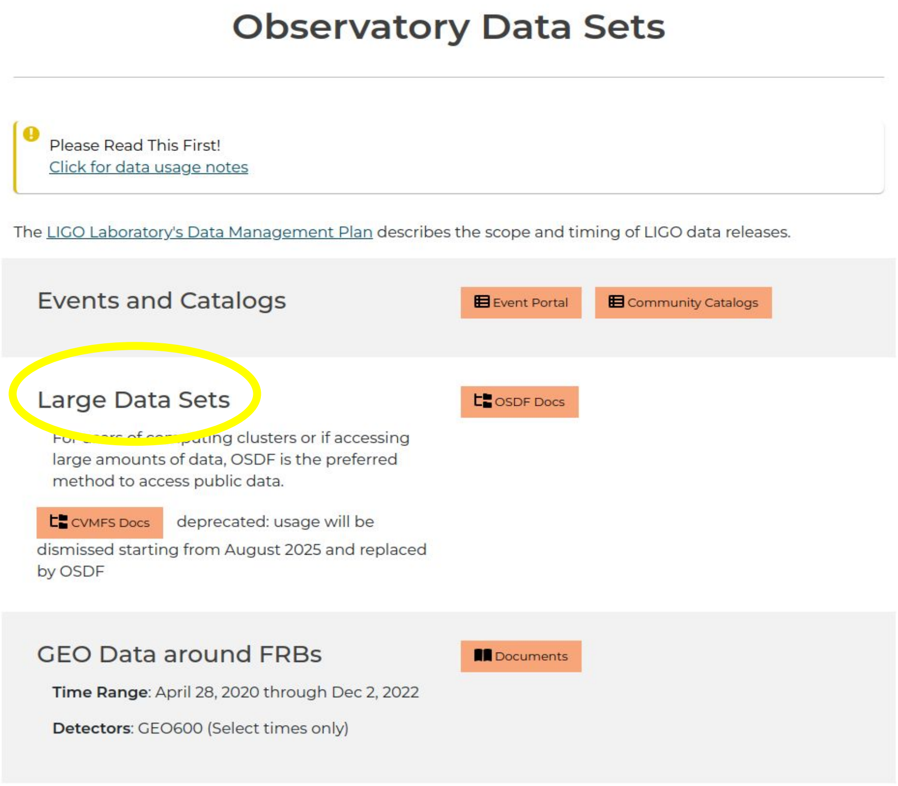
GPS Time Interval: [1256655618, 1269363618]

Detector: H1

Note:

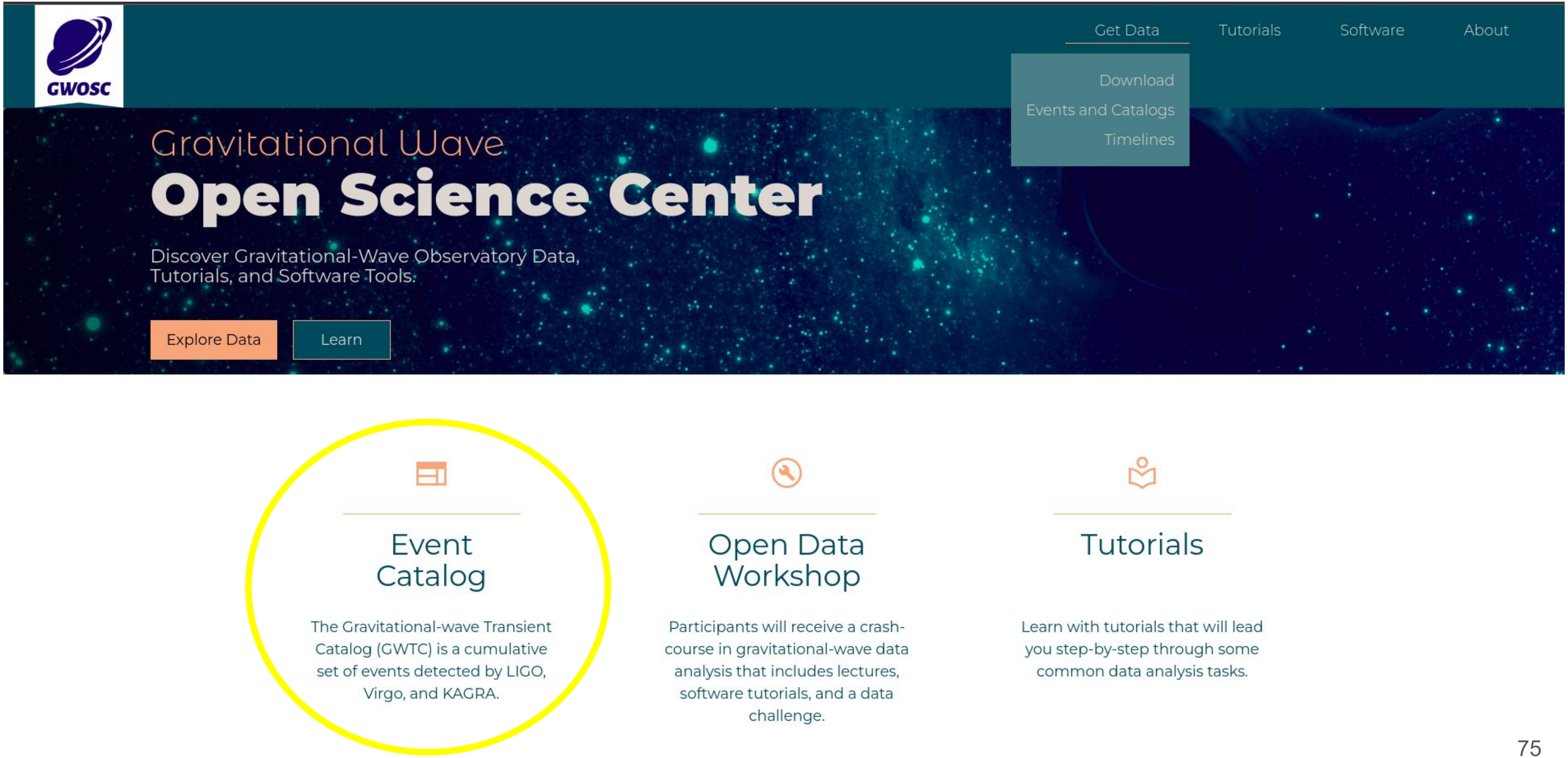
- Each file covers a 4096-second period, with strain data at either 16kHz or downsampled to 4 kHz.
- The time of the beginning of the file is shown as 'GPS start time', and is linked to a timeline showing which parts of the tile have science-mode data.
- The last column of the table shows the percentage of each file that has data.
- For instructions on downloading many files, see the Automatic Download Tutorial.

Timeline	UTC	Mbytes	HDF5	Frame	Percent
1256660992	2019-11-01T16:29:34	50.4 MB	HDF5	Frame	40.2
1256665088	2019-11-01T17:37:50	124.3 MB	HDF5	Frame	100.0
1256669184	2019-11-01T18:46:06	124.3 MB	HDF5	Frame	100.0
1256673280	2019-11-01T19:54:22	124.3 MB	HDF5	Frame	100.0
1256677376	2019-11-01T21:02:38	62.4 MB	HDF5	Frame	49.9
1256681472	2019-11-01T22:10:54	84.4 MB	HDF5	Frame	67.7
1256685568	2019-11-01T23:19:10	65.0 MB	HDF5	Frame	52.0
1256689664	2019-11-02T00:27:26	124.3 MB	HDF5	Frame	100.0
1256693760	2019-11-02T01:35:42	124.3 MB	HDF5	Frame	100.0



- To download large datasets : **CernVM File System (CVMFS)**

- Large datasets accessed together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Discover Gravitational-Wave Observatory Data, Tutorials, and Software Tools.
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The Gravitational-wave Transient Catalog (GWTC) is a cumulative set of gravitational wave transients maintained by the LIGO/Virgo/KAGRA collaboration. The online GWTC contains confidently-detected events from multiple data releases. For further information, see documentation for individual releases: GWTC-1, GWTC-2, GWTC-2.1, and GWTC-3.

Note, this catalog is only updated periodically, and may not contain recently published events. For the most recent events, you can browse all available events.

Previous versions of this catalog are archived in zenodo.

- Toggle columns on/off with Display button at right.
- Click an event name for all versions and more information.
- Values in the table below are from the **Default SEARCH** and **Default PE** cases found in the individual event's page.
- See Event Portal Usage Notes for more details.

List contains 93 events.

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GWTC-2, C

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GWTC-3 Data Release Documentation

- Toggle
- Click an
- Values i
- See Eve

List contains 9

Description

This data release is described in: GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run. GWTC-3 is a cumulative catalog describing all the gravitational-wave transients found in observing run O3b. This page provides documentation for the confident and marginal events found in O3b. Comparable information for earlier event releases may be found by following the links for GWTC-1, GWTC-2, and GWTC-2.1 (where the latest information for O1, O2, and O3a may be found).

Here we provide the strain and data quality for GWTC-3-confident events and the GWTC-3-marginal candidates described in Tables I and II of the GWTC-3 catalog paper. Search results for FAR, SNR and P_astro are provided for all events and marginal candidates.

Table I of the GWTC-3 catalog paper lists 35 probable events that were found by at least one search algorithm with probability of astrophysical origin assuming a compact binary coalescence source (P_astro) greater than 0.5. The strain, segments, search results and parameter estimation values with corresponding 90% credible intervals are listed in GWTC-3-confident. For candidates identified by the minimally modeled cWB search analysis, we additionally require that a candidate be found by one of the templated-based analysis with P_astro > 0.1, since cWB can detect many types of signal, and additional verification is needed for the assumption of a compact binary coalescence source.

Table II in the GWTC-3 catalog paper presents 7 marginal candidates with P_astro that does not satisfy the criteria for Table I, but were found with a FAR below a threshold of 2 per year in at least one analysis. The strain, segments and search results for these 7 are listed in GWTC-3-marginal. The GW prefix is omitted when a plausible instrumental origin has been identified.

Displayed in the "Event List Views" for both the GWTC-3-confident and GWTC-3-marginal are the lowest false alarm rate and highest P_astro value taken across all search pipelines. The SNR value displayed is taken from the default PE result, or in the cases where no PE results are provided, the highest SNR from the search pipelines. Additional results can be found by clicking each event. See Event Portal Usage Notes for more details.

List contains 93 events.

Event nomenclature - GWYYMMDD_UTCtime

Focus

Display all | Display

Name	Version	Release	GPS	Mass 1 ($M_\odot$)	Mass 2 ($M_\odot$)	Network SNR	Distance (Mpc)	χ_{eff}	Total Mass ($M_\odot$)
GW200322_091133	v1	GWTC-3-confident	1268903511.3	38^{+130}_{-22}	$11.3^{+24.3}_{-6.0}$	$4.5^{+2.7}_{-3.0}$	3500^{+12500}_{-2200}	$0.27^{+0.54}_{-0.58}$	50^{+132}_{-22}
GW200316_215756	v1	GWTC-3-confident	1268431094.1	$13.1^{+10.2}_{-2.9}$	$7.8^{+2.0}_{-2.9}$	$10.3^{+0.4}_{-0.7}$	1120^{+480}_{-440}	$0.13^{+0.27}_{-0.10}$	$21.2^{+7.2}_{-2.0}$
GW200311_115853	v1	GWTC-3-confident	1267963151.3	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$17.8^{+0.2}_{-0.2}$	1170^{+280}_{-400}	$-0.02^{+0.16}_{-0.20}$	$61.9^{+5.3}_{-4.2}$
GW200308_173609	v1	GWTC-3-confident	1267724187.7	60^{+166}_{-29}	24^{+36}_{-13}	$4.7^{+2.5}_{-2.9}$	7100^{+13900}_{-4400}	$0.16^{+0.58}_{-0.49}$	$92.0^{+169.0}_{-48.0}$
GW200306_093714	v1	GWTC-3-confident	1267522652.1	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$7.8^{+0.4}_{-0.6}$	2100^{+1700}_{-1100}	$0.32^{+0.28}_{-0.46}$	$43.9^{+11.8}_{-7.5}$
GW200302_015811	v1	GWTC-3-confident	1267149509.5	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$10.8^{+0.3}_{-0.4}$	1480^{+1020}_{-700}	$0.01^{+0.25}_{-0.26}$	$57.8^{+9.6}_{-6.9}$
GW200225_060421	v1	GWTC-3-confident	1266645879.3	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$12.5^{+0.3}_{-0.4}$	1150^{+510}_{-530}	$-0.12^{+0.17}_{-0.28}$	$33.5^{+3.6}_{-3.0}$
GW200224_222234	v1	GWTC-3-confident	1266618172.4	$40.0^{+6.7}_{-4.5}$	$32.7^{+4.8}_{-7.2}$	$20.0^{+0.2}_{-0.2}$	1710^{+500}_{-650}	$0.10^{+0.15}_{-0.16}$	$72.3^{+7.2}_{-5.3}$
GW200220_124850	v1	GWTC-3-confident	1266238148.1	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$8.5^{+0.3}_{-0.5}$	4000^{+2800}_{-2200}	$-0.07^{+0.27}_{-0.33}$	67^{+17}_{-12}
GW200220_061928	v1	GWTC-3-confident	1266214786.7	87^{+40}_{-23}	61^{+26}_{-25}	$7.2^{+0.4}_{-0.7}$	6000^{+4800}_{-3100}	$0.06^{+0.40}_{-0.38}$	148^{+55}_{-33}
GW200219_094415	v1	GWTC-3-confident	1266140673.1	$37.5^{+10.1}_{-6.9}$	$27.9^{+7.4}_{-8.4}$	$10.7^{+0.3}_{-0.5}$	3400^{+1700}_{-1500}	$-0.08^{+0.23}_{-0.29}$	$65.0^{+12.6}_{-8.2}$
GW200216_220804	v1	GWTC-3-confident	1265926102.8	51^{+22}_{-13}	30^{+14}_{-16}	$8.1^{+0.4}_{-0.5}$	3800^{+3000}_{-2000}	$0.10^{+0.34}_{-0.36}$	81^{+20}_{-14}
GW200210_092254	v1	GWTC-3-confident	1265361792.9	$24.1^{+7.5}_{-4.6}$	$2.83^{+0.47}_{-0.42}$	$8.4^{+0.5}_{-0.7}$	940^{+430}_{-340}	$0.02^{+0.22}_{-0.21}$	$27.0^{+7.1}_{-4.3}$
GW200209_085452	v1	GWTC-3-confident	1265273710.1	$35.6^{+10.5}_{-6.8}$	$27.1^{+7.8}_{-7.8}$	$9.6^{+0.4}_{-0.5}$	3400^{+1900}_{-1800}	$-0.12^{+0.24}_{-0.30}$	$62.6^{+13.9}_{-9.4}$
GW200208_222617	v1	GWTC-3-confident	1265235995.9	51^{+103}_{-30}	$12.3^{+9.2}_{-5.5}$	$7.4^{+1.4}_{-1.2}$	4100^{+4400}_{-2000}	$0.45^{+0.42}_{-0.46}$	63^{+100}_{-26}
GW200208_130117	v1	GWTC-3-confident	1265202095.9	$37.7^{+9.3}_{-6.2}$	$27.4^{+6.3}_{-7.3}$	$10.8^{+0.3}_{-0.4}$	2230^{+1020}_{-850}	$-0.07^{+0.21}_{-0.27}$	$65.3^{+8.1}_{-6.8}$
GW200202_154313	v1	GWTC-3-confident	1264693411.5	$10.1^{+3.5}_{-1.4}$	$7.3^{+1.1}_{-1.7}$	$10.8^{+0.2}_{-0.4}$	410^{+150}_{-160}	$0.04^{+0.13}_{-0.06}$	$17.58^{+1.78}_{-0.67}$


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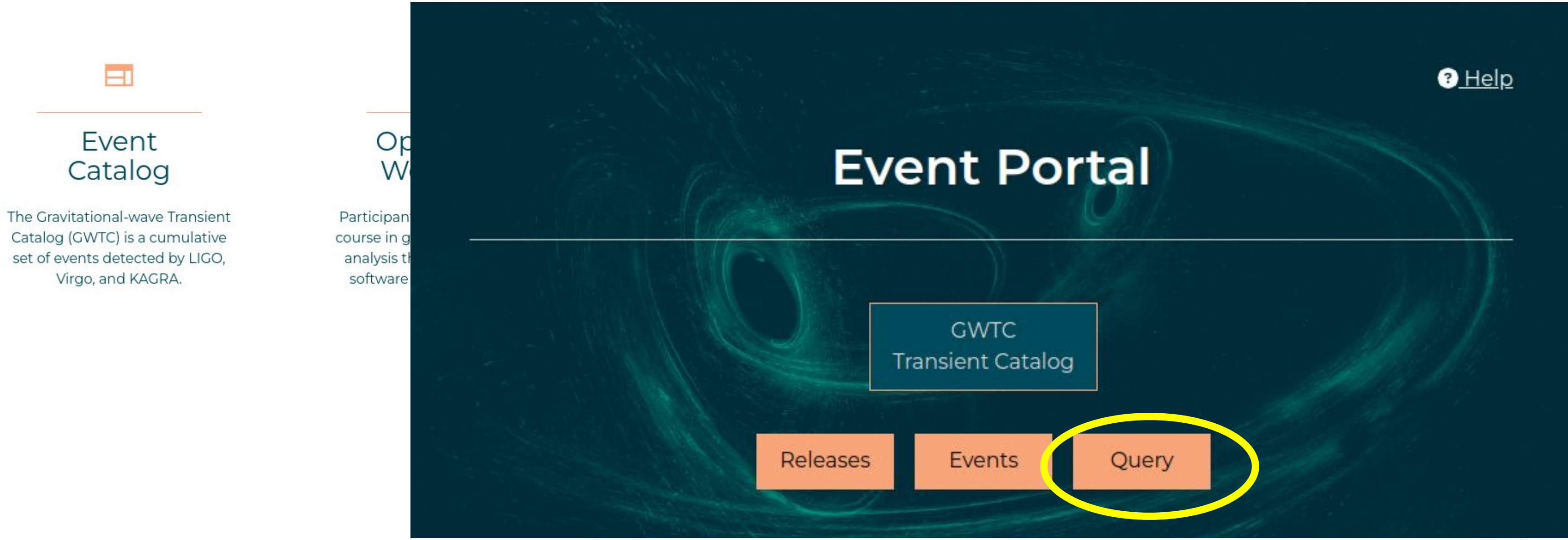
Event Catalog
The Gravitational-wave Transient Catalog (GWTC) is a cumulative set of events detected by LIGO, Virgo, and KAGRA.
Help
Event Portal
GWTC
Transient Catalog
Releases
Events
Query

Query Events

Event Name:

The (partial) name of the event, e.g. GW150914

Release:

- Initial_LIGO_Virgo
- GWTC-1-confident
- GWTC-1-marginal
- O1_O2-Preliminary

Restrict search to a Catalog Release

Mass 1 Range:	0	∞	Mass 2 Range:	0	∞
Total Mass Range:	0	∞	Final Mass Range:	0	∞
Chirp Mass Range:	0	∞	Detector Frame Chirp Mass Range:	0	∞
Distance (Mpc) Range:	0	∞	Redshift Range:	0	∞
Network SNR Range:	0	∞	χ_{eff} Range:	-1	1
False Alarm Rate Range:	0	∞	P_{astro} Range:	0	1

Release:

- Initial_LIGO_Virgo
- GWTC-1-confident
- GWTC-1-marginal
- O1_O2-Preliminary

Restrict search to a Catalog Release

Mass 1 Range:	0	∞	Mass 2 Range:	0	∞
Total Mass Range:	0	∞	Final Mass Range:	0	∞
Chirp Mass Range:	0	∞	Detector Frame Chirp Mass Range:	0	∞
Distance (Mpc) Range:	0	∞	Redshift Range:	0	∞
Network SNR Range:	0	∞	χ_{eff} Range:	-1	1
False Alarm Rate Range:	0	∞	P_{astro} Range:	0	1

UTC Time Range:

GPS Time Range:

Show only last version

Output Format: HTML JSON CSV ASCII

Submit

List contains 93 events.

Focus

Display all | Display

Name	Version	Release	GPS	Mass 1 ($M_\odot$)	Mass 2 ($M_\odot$)	Network SNR	Distance (Mpc)	χ_{eff}	Total Mass ($M_\odot$)
GW200322_091133	v1	GWTC-3-confident	1268903511.3	38^{+130}_{-22}	$11.3^{+24.3}_{-6.0}$	$4.5^{+2.7}_{-3.0}$	3500^{+12500}_{-2200}	$0.27^{+0.54}_{-0.58}$	50^{+132}_{-22}
GW200316_215756	v1	GWTC-3-confident	1268431094.1	$13.1^{+10.2}_{-2.9}$	$7.8^{+2.0}_{-2.9}$	$10.3^{+0.4}_{-0.7}$	1120^{+480}_{-440}	$0.13^{+0.27}_{-0.10}$	$21.2^{+7.2}_{-2.0}$
GW200311_115853	v1	GWTC-3-confident	1267963151.3	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$17.8^{+0.2}_{-0.2}$	1170^{+280}_{-400}	$-0.02^{+0.16}_{-0.20}$	$61.9^{+5.3}_{-4.2}$
GW200308_173609	v1	GWTC-3-confident	1267724187.7	60^{+166}_{-29}	24^{+36}_{-13}	$4.7^{+2.5}_{-2.9}$	7100^{+13900}_{-4400}	$0.16^{+0.58}_{-0.49}$	$92.0^{+169.0}_{-48.0}$
GW200306_093714	v1	GWTC-3-confident	1267522652.1	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$7.8^{+0.4}_{-0.6}$	2100^{+1700}_{-1100}	$0.32^{+0.28}_{-0.46}$	$43.9^{+11.8}_{-7.5}$
GW200302_015811	v1	GWTC-3-confident	1267149509.5	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$10.8^{+0.3}_{-0.4}$	1480^{+1020}_{-700}	$0.01^{+0.25}_{-0.26}$	$57.8^{+9.6}_{-6.9}$
GW200225_060421	v1	GWTC-3-confident	1266645879.3	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$12.5^{+0.3}_{-0.4}$	1150^{+510}_{-530}	$-0.12^{+0.17}_{-0.28}$	$33.5^{+3.6}_{-3.0}$
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All events in that catalogue

GW200224_222234

Documentation

Release: GWTC-3-confident

Event UID: GW200224_222234-v1

Names: GW200224_222234

GPS: 1266618172.4

UTC Time: 2020-02-24 22:22:34

GraceDB: S200224ca

GCN: Query for Circulars · Notices

Timeline: Query for segments

DOI: https://doi.org/10.7935/b024-1886

Data sourced from frame channels.

FrameChannels: [H1:DCS-CALIB_STRAIN_CLEAN_SUB60HZ_C01, L1:DCS-CALIB_STRAIN_CLEAN_SUB60HZ_C01, V1:Hrec_hoft_16384Hz]

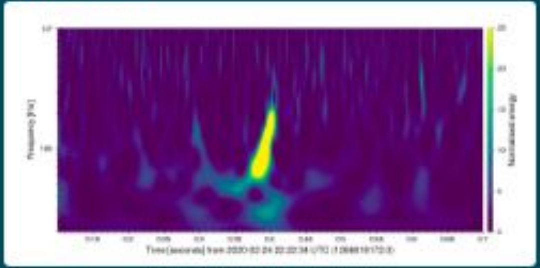
Data sourced from frame types:

FrameTypes: [H1_HOFT_CLEAN_SUB60HZ_C01, L1_HOFT_CLEAN_SUB60HZ_C01, V1Online]

To open GWF files, use channels names as shown for GWTC-1: https://doi.org/10.7935/82H3-HH23

Type of data used to detect this event →

H1 strain



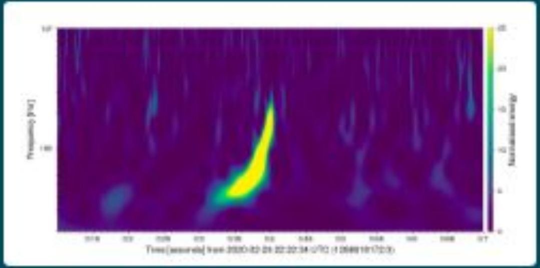
32sec · 16KHz: GWF HDF TXT

32sec · 4KHz: GWF HDF TXT

4096sec · 16KHz: GWF HDF TXT

4096sec · 4KHz: GWF HDF TXT

L1 strain



32sec · 16KHz: GWF HDF TXT

32sec · 4KHz: GWF HDF TXT

4096sec · 16KHz: GWF HDF TXT

4096sec · 4KHz: GWF HDF TXT

GWTC-3 PE for GW200224_222234

Waveform Family: C01:Mixed

Date added: Nov. 1, 2021

show / hide parameters

Source File

Posterior Samples in Zenodo

Skymap for GW200224_222234

GWTC-3 PE for GW200224_222234 (update)

Waveform Family: C01:Mixed

Date added: June 23, 2023

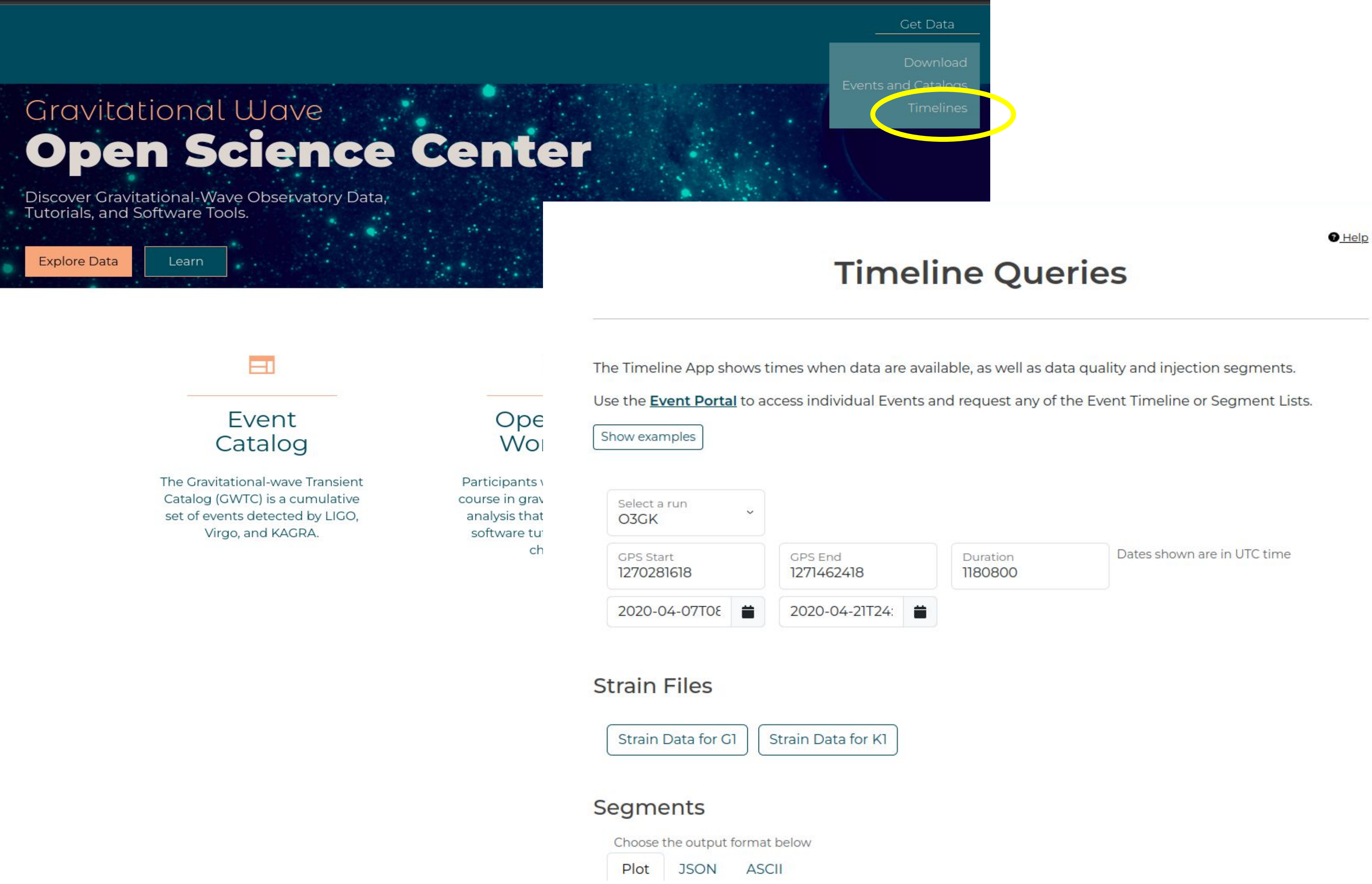
show / hide parameters

Source File

Posterior Samples in Zenodo

Skymap for GW200224_222234

Default PE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Event Catalog
The Gravitational-wave Transient Catalog (GWTC) is a cumulative set of events detected by LIGO, Virgo, and KAGRA.
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Timeline Queries
The Timeline App shows times when data are available, as well as data quality and injection segments.
Use the Event Portal to access individual Events and request any of the Event Timeline or Segment Lists.
Show examples
Select a run
O3GK
GPS Start
1270281618
GPS End
1271462418
Duration
1180800
Dates shown are in UTC time
Strain Files
Strain Data for G1
Strain Data for K1
Segments
Choose the output format below
Plot
JSON
ASCII

Segments

Choose the output format below

Plot | JSON | ASCII

Display

- [ ] G1_BURST_CAT1
- [ ] G1_BURST_CAT2
- [ ] G1_BURST_CAT3
- [ ] G1_CBC_CAT1
- [ ] G1_CBC_CAT2
- [ ] G1_CBC_CAT3
- [x] G1_DATA
- [ ] G1_NO_BURST_HW_INJ
- [ ] G1_NO_CBC_HW_INJ
- [ ] G1_NO_CW_HW_INJ
- [ ] G1_NO_DETCHAR_HW_INJ

- [ ] K1_BURST_CAT1
- [ ] K1_BURST_CAT2
- [ ] K1_BURST_CAT3
- [ ] K1_CBC_CAT1
- [ ] K1_CBC_CAT2
- [ ] K1_CBC_CAT3
- [ ] K1_DATA
- [ ] K1_NO_BURST_HW_INJ
- [ ] K1_NO_CBC_HW_INJ
- [ ] K1_NO_CW_HW_INJ
- [ ] K1_NO_DETCHAR_HW_INJ

Timeline O3GK

From: 2020-04-07T08:00:00 (GPS=1270281618)

To: 2020-04-21T00:00:00 (GPS=1271462418)

Duration: 1180800 s

Strain Data for G1 | Strain Data for K1

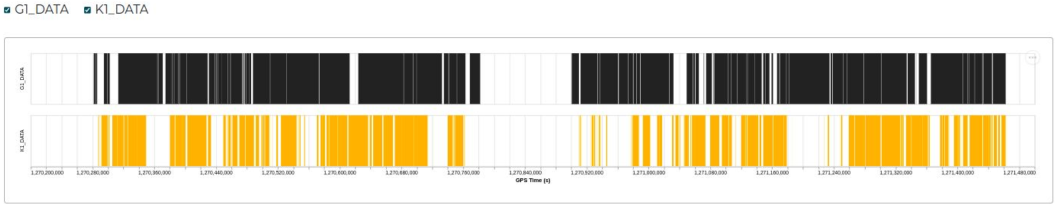
Timeline Stats

	Time Active	Duty Cycle	Segments
G1_DATA	940133 s	79.62%	94
K1_DATA	628055 s	53.19%	155

Download Segments

JSON | ASCII

G1_DATA | K1_DATA



Getting idea of whether the detector was operating and if yes, at what data quality level

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Source Visibility Check
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Event Catalog

The Gravitational-wave Transient Catalog (GWTC) is a cumulative set of events detected by LIGO, Virgo, and KAGRA.

Open Data Workshop

Participants will receive a crash-course in gravitational-wave data analysis that includes lectures, software tutorials, and a data challenge.

Tutorials

Learn with tutorials that will lead you step-by-step through some common data analysis tasks.

GWOSC API

Browse API v2 | Version 2 docs | Version 1 docs

The second iteration of GWOSC API is now public and ready to use! We recommend upgrading now to take full advantage of the improvements. Scroll down to learn more.

The Gravitational Wave Open Science Center enables programmatic access to data on observation runs, event catalogs, single event detections, parameter estimations, data quality and injection segments, and strain datasets and statistics. This API is intended for researchers, students, educators and the general public to fetch structured data in automated scripts, web apps, or other computer programs.

All API URL endpoints are read-only, this means that all requests to fetch data should use the `GET` HTTP method. Other HTTP methods will return 40x error responses.

This public API does not require any authentication. All URL endpoints are also authorized for Cross-Origin Resource Sharing (CORS), this means that resources can be fetched from web apps running on web browsers.

The data is available mostly in JSON format, with some endpoints allowing for CSV or ASCII format.

If you need help using this API, you can ask for help in the gravitational wave community forum.

Interacting with the API

For Python projects, we recommend installing the gwosc Python client to fetch data.

```
pip install gwosc
```

Below are three examples on how to fetch data from our API in different languages. In all of them, we show

Gravitational Wave Detector Network

Operational Snapshot as of Jul 26, 03:32 UTC -- Network summary

A status display including Virgo is at online.ligo.org

Detector	Status	Duration	
GEO 600	Observing	1:44	GEOdcPlots SummaryReports
LIGO Hanford	Observing	2:18	SummaryPages
LIGO Livingston	Observing	3:35	SummaryPages
Virgo	Not tracked here		StatusPage VIM
KAGRA	Not tracked here		SummaryPages

Detector status summary pages   Hide LVK links

GWIStat

GWOSC Calendar Today Yesterday O4 summary Previous Observing Runs

Gravitational-Wave Observatory Status

Please select a date from the calendar above to see archived or current status.

Information is available for dates after November 30, 2016. The Advanced LIGO and Virgo detectors have begun the third part of the fourth observing run, known as O4c, as of January 28, 2024. The entry of the KAGRA detector into O4c has been postponed in order to continue detector commissioning activities and further increase the sensitivity of the detector. All detectors are planned to rejoin O4 by the end of the run. Summaries of the current observing run and previous observing runs are available in the menu above. For overviews of LIGO, Virgo, and KAGRA observing runs, see the arXiv:1304.0670.

- **Today's Summary Page**
- Current Status (GWISTAT)
- LIGO/Virgo Alerts (GraceDB)
- Hanford alog – Livingston alog – Virgo logbook – KAGRA klog
- LIGO Laboratory – Virgo – KAGRA Observatory – GEO600


LIGO Hanford


LIGO Livingston


Virgo


KAGRA


GEO600

gwistat

Last 90 days 5s

Gravitational Wave Detector Network

Operational Snapshot as of May 10, 2025 05:20:02 UTC

Detector	Status	Duration [hh:mm]	Latency [s]
GEO600	Info too old	>99:00	
LIGO Hanford	Down	>99:00	43
LIGO Livingston	Down	>99:00	61
Virgo	Down	>99:00	21
KAGRA	Down	>99:00	36

GstLAL Inspiral Detector Range History (Mpc)

Info and Links

More information about this page can be found at the wiki.

For details about the range estimation see the following pages:

- Range Calculation
- PSD Estimation

Bug reports, comments, and feature requests are welcome at: https://git.ligo.org/lscsoft/gwistat/-/issues.

Last 5 minutes 5s

Absolute time range

From

now-5m

To

now

Apply time range

It looks like you haven't used this time picker before. As soon as you enter some time intervals, recently used intervals will appear here.
Read the documentation to find out more about how to enter custom time ranges.

Search quick ranges

- Last 5 minutes
- Last 15 minutes
- Last 30 minutes
- Last 1 hour
- Last 3 hours
- Last 6 hours
- Last 12 hours
- Last 24 hours
- Last 2 days

Browser Time IST UTC+05:30 Change time settings

GraceDB Public Alerts Latest Search Documentation Login

Please log in to view full database contents.

gracedb.ligo.org

GraceDB Overview

The **Gra**vitational-Wave **C**andidate **E**vent **D**ata**b**ase (**GraceDB**) is a service operated by the LIGO Scientific Collaboration. It provides a centralized location for aggregating and retrieving information about candidate gravitational-wave events. GraceDB provides an API for programmatic access, and a client package is available for interacting with the API.

Useful information

- Information about GW alerts and real-time data products is available in the LIGO/Virgo Public Alert Guide.
- Real-time status of the LIGO Data Grid (LVK Credentials Required).
- Need help? Send an email to computing-help@ligo.org, or LIGO/Virgo users can report issues on the GraceDB Gitlab page.

GraceDB Notifications

GraceDB notifies registered users of Gravitational-Wave candidate detections in real-time during LIGO/Virgo/KAGRA observation periods. Current notifications mechanisms are:

- Phone alerts (calls/SMS) are enabled
- Email alerts are enabled
- `igwn-alert` messages to `kafka://kafka.scimma.org/` are enabled
  - Messages are sent to group: `gracedb`

Server code version: 2.31.1

LIGO/Virgo/KAGRA Public Alerts

- More details about public alerts are provided in the LIGO/Virgo/KAGRA Alerts User Guide.
- Retractions are marked in red. Retraction means that the candidate was manually vetted and is no longer considered a candidate of interest.
- Less-significant events are marked in grey, and are not manually vetted. Consult the LVK Alerts User Guide for more information on significance in O4.
- Less-significant events are not shown by default. Press "**Show All Public Events**" to show significant and less-significant events.

O4 Significant Detection Candidates: **203** (228 Total - 25 Retracted)

O4 Low Significance Detection Candidates: **3781** (Total)

Show All Public Events

Page 1 of 16. next last »

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Commen
S250331o	BBH (>99%)	Yes	March 31, 2025 01:34:48 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years	
S250328ae	BBH (>99%)	Yes	March 28, 2025 05:40:27 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years	

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Comments
S250331o	BBH (>99%)	Yes	March 31, 2025 01:34:48 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years	
S250328ae	BBH (>99%)	Yes	March 28, 2025 05:40:27 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years	
S250326y	BBH (>99%)	Yes	March 26, 2025 01:54:06 UTC	GCN Circular Query Notices | VOE		1 per 8890.9 years	
S250319bu	BBH (>99%)	Yes	March 19, 2025 06:25:36 UTC	GCN Circular Query Notices | VOE		1 per 67.634 years	
S250306ej	Terrestrial (>99%)	Yes	March 6, 2025 15:00:44 UTC	GCN Circular Query Notices | VOE		2.9257 per year	RETRACTED
S250304cb	BBH (96%), Terrestrial (4%)	Yes	March 4, 2025 06:22:45 UTC	GCN Circular Query Notices | VOE		1.7738 per year	
S250227y	Terrestrial (99%), BNS (1%)	Yes	Feb. 27, 2025 01:02:25 UTC	GCN Circular Query Notices | VOE		1.2963 per year	RETRACTED
S250227e	BBH (52%), Terrestrial (48%)	Yes	Feb. 27, 2025 00:12:45 UTC	GCN Circular Query Notices | VOE		1 per 12215 years	

IGWN | Public Alerts User Guide

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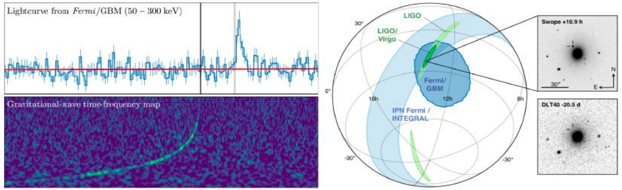
- Observing Capabilities
- Data Analysis
- Alert Contents
- Sample Code
- Additional Resources
- Early-Warning Alerts
- Change Log
- Glossary

Question? Issues? Feedback?

Email emfollow-userguide@support.ligo.org

LIGO/Virgo/KAGRA Public Alerts User Guide

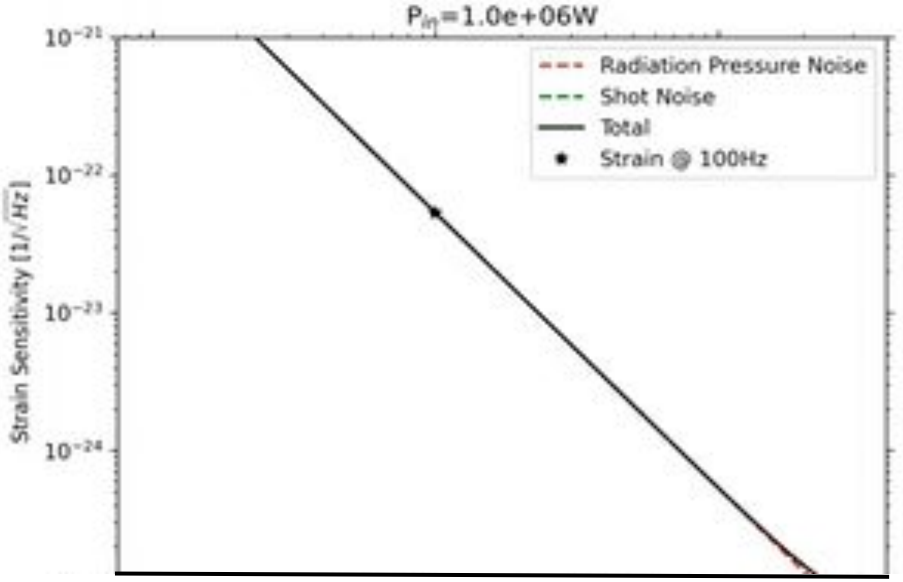


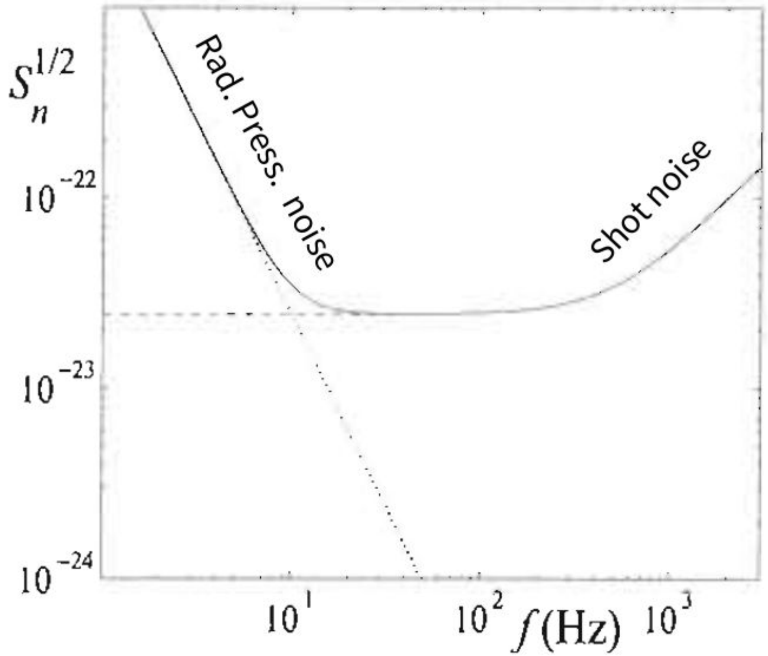
Welcome to the LIGO/Virgo/KAGRA Public Alerts User Guide! This document is intended for both professional astronomers and science enthusiasts who are interested in receiving alerts and real-time data products related to gravitational-wave (GW) events.

Four sites (LHO, LLO, Virgo, KAGRA) together form a global network of ground-based GW detectors. The LIGO Scientific Collaboration, the Virgo Collaboration, and the KAGRA Collaboration jointly analyze the data in real time to detect and localize transients from compact binary mergers and other sources. When a signal candidate is found, an alert is sent to astronomers in order to search for counterparts (electromagnetic waves or neutrinos).

THANK YOU

Shot noise and radiation pressure noise

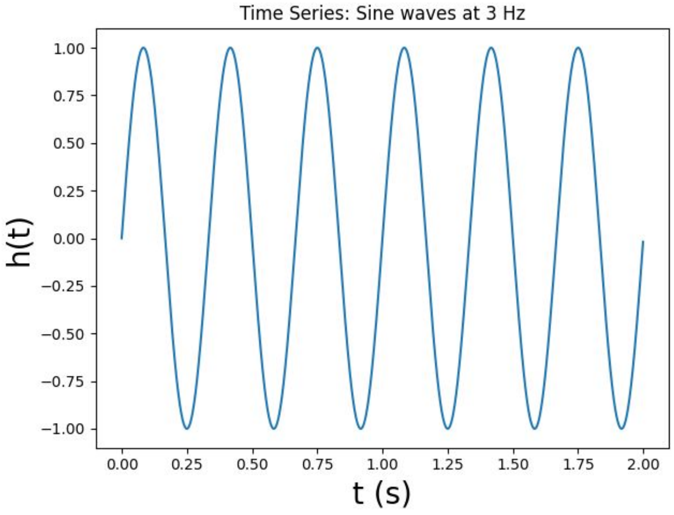




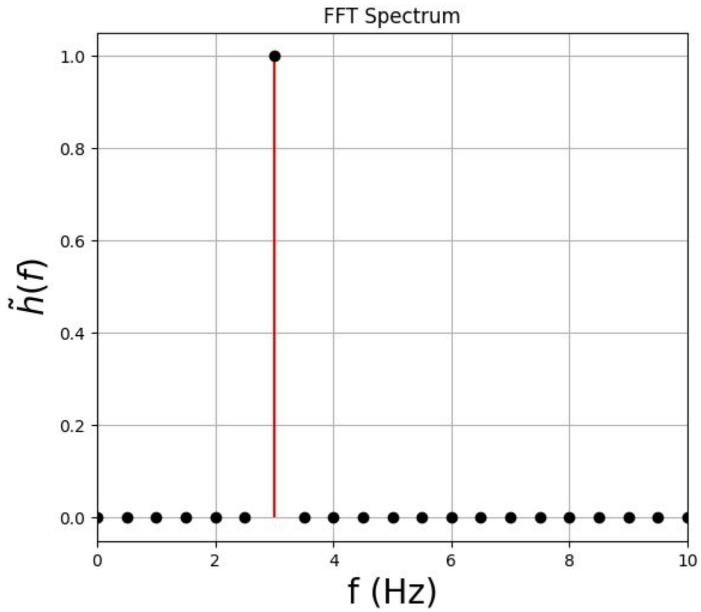
Source: life around science

Fourier Transform

$$\tilde{h}(f) = \int_{-\infty}^{\infty} h(t)e^{-2\pi i f t}dt$$



Fourier Transform



Standard Quantum Limit

Shot Noise

laser power

radiation pressure noise

Balance out Shot noise and Radiation noise
(Standard quantum limit)