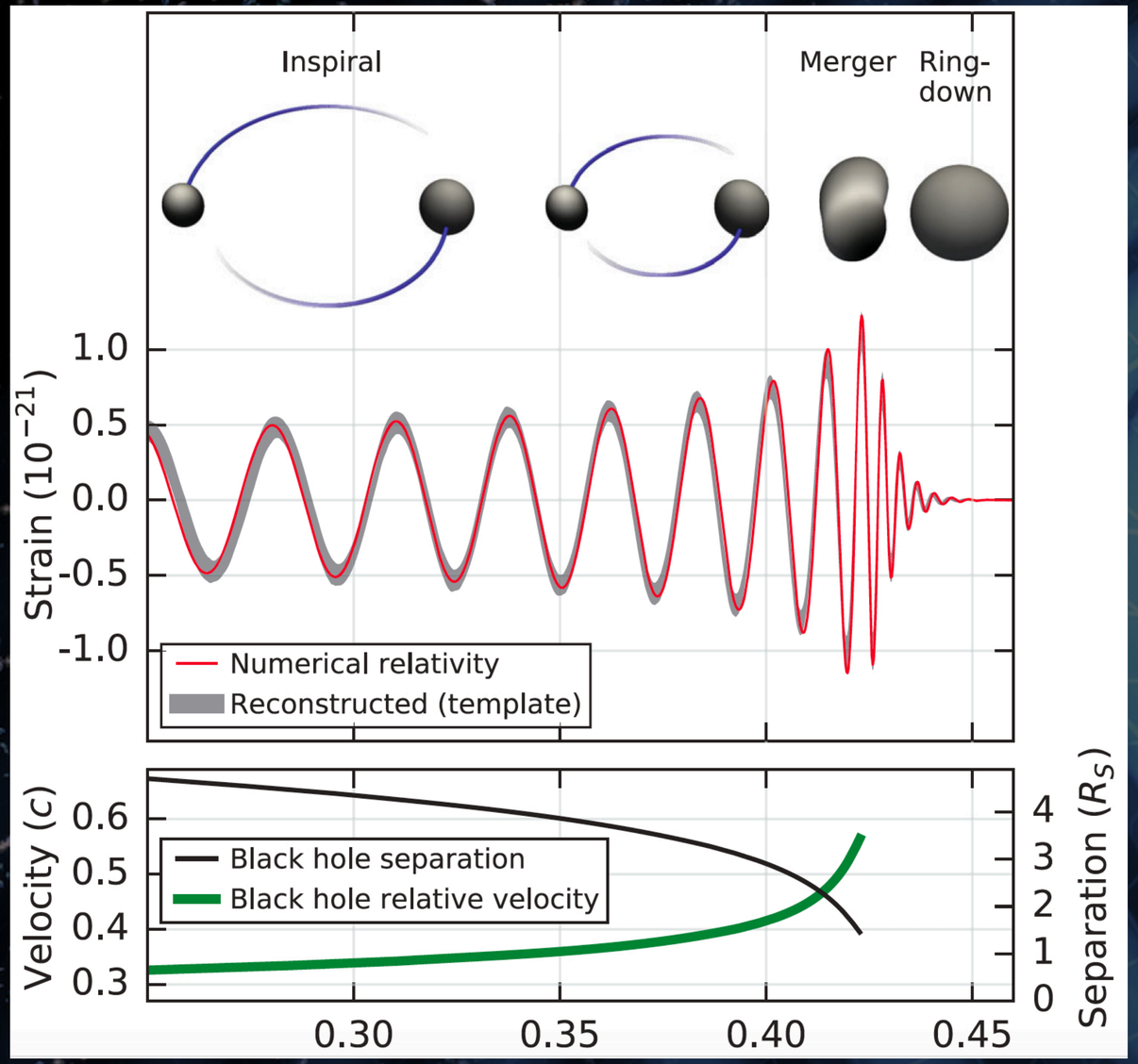
GWOSC: Gravitational Wave Open Science Center

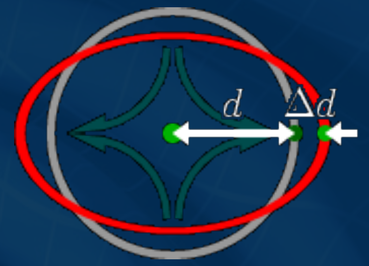
Agata Trovato on behalf of the LIGO and Virgo Collaborations
APC, CNRS/IN2P3, Univ. De Paris

DCC number: G2100144

Gravitational waves (GW)



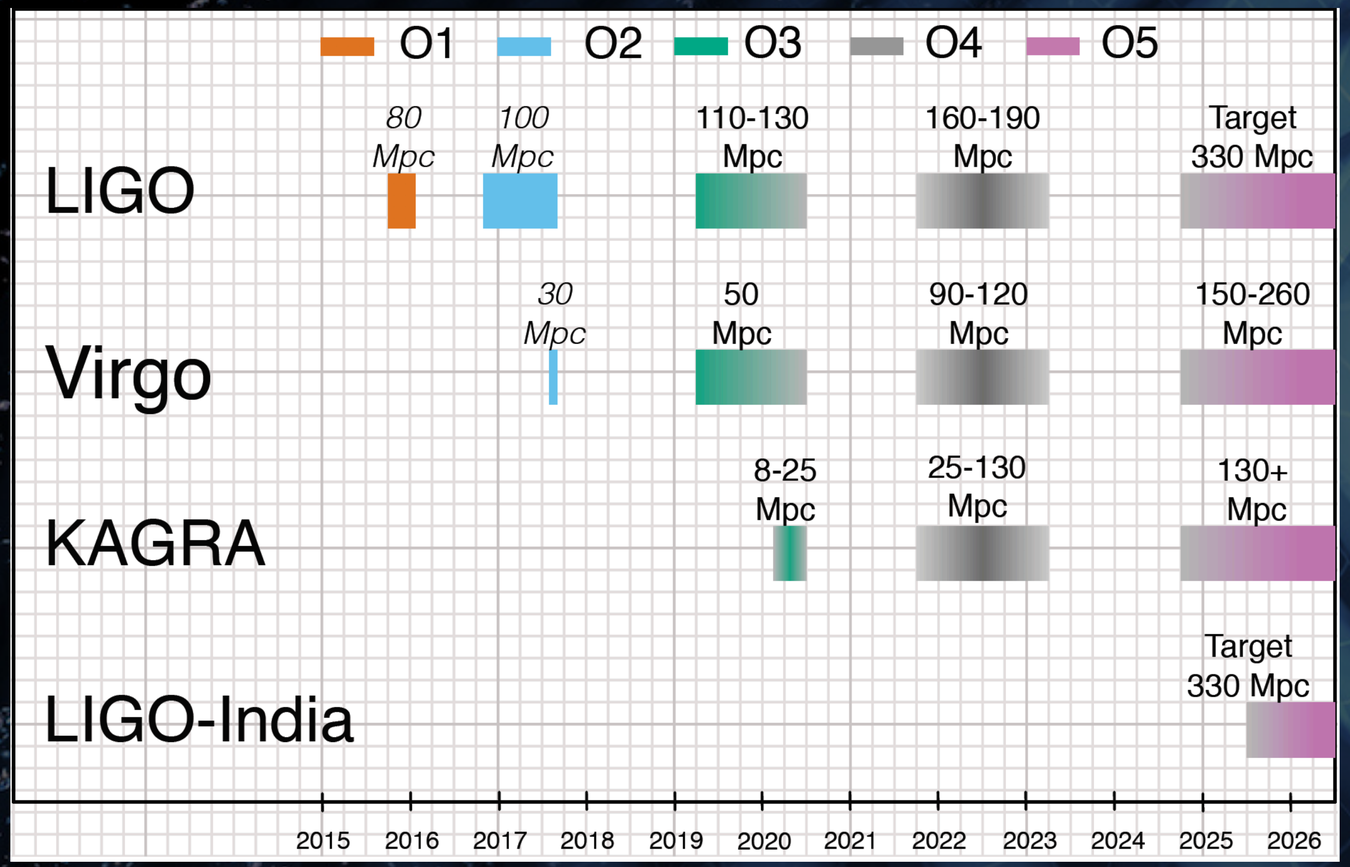
Reminder: strain



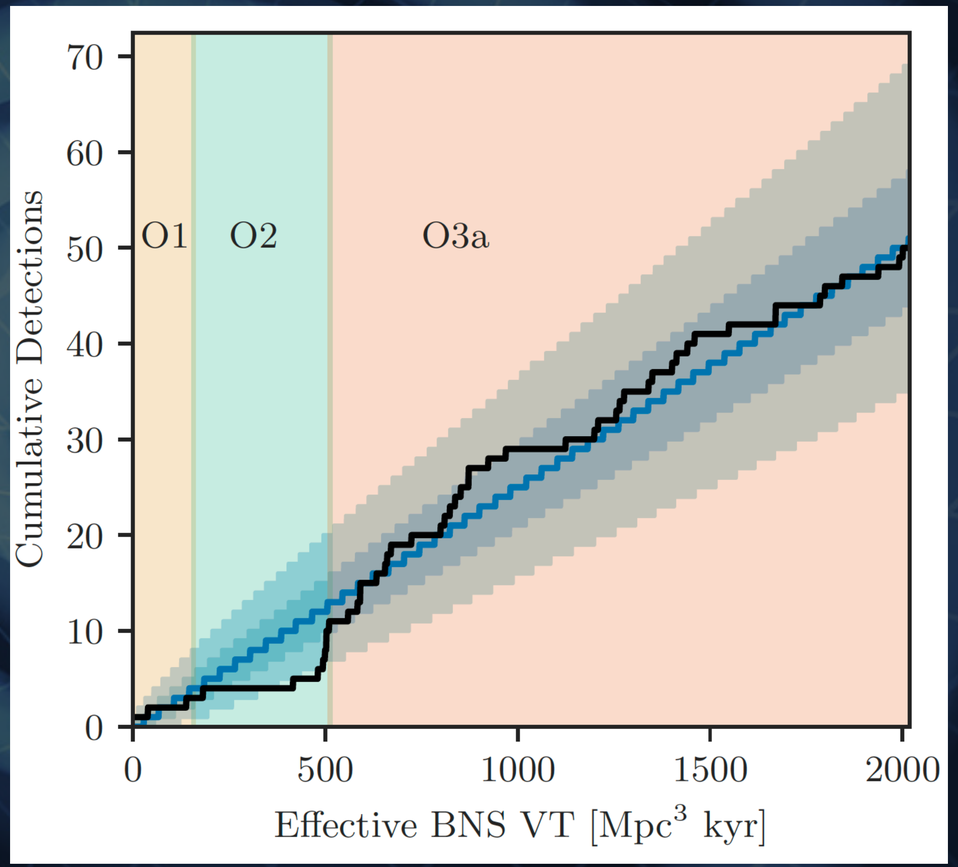
$$h = \frac{\Delta d}{d} = \frac{change\ in\ relative\ position}{separation}$$

Observing runs and detections

The detectors alternate periods of data taking and periods of upgrades to the machines



Cumulative number of transient GW events detected and published until now



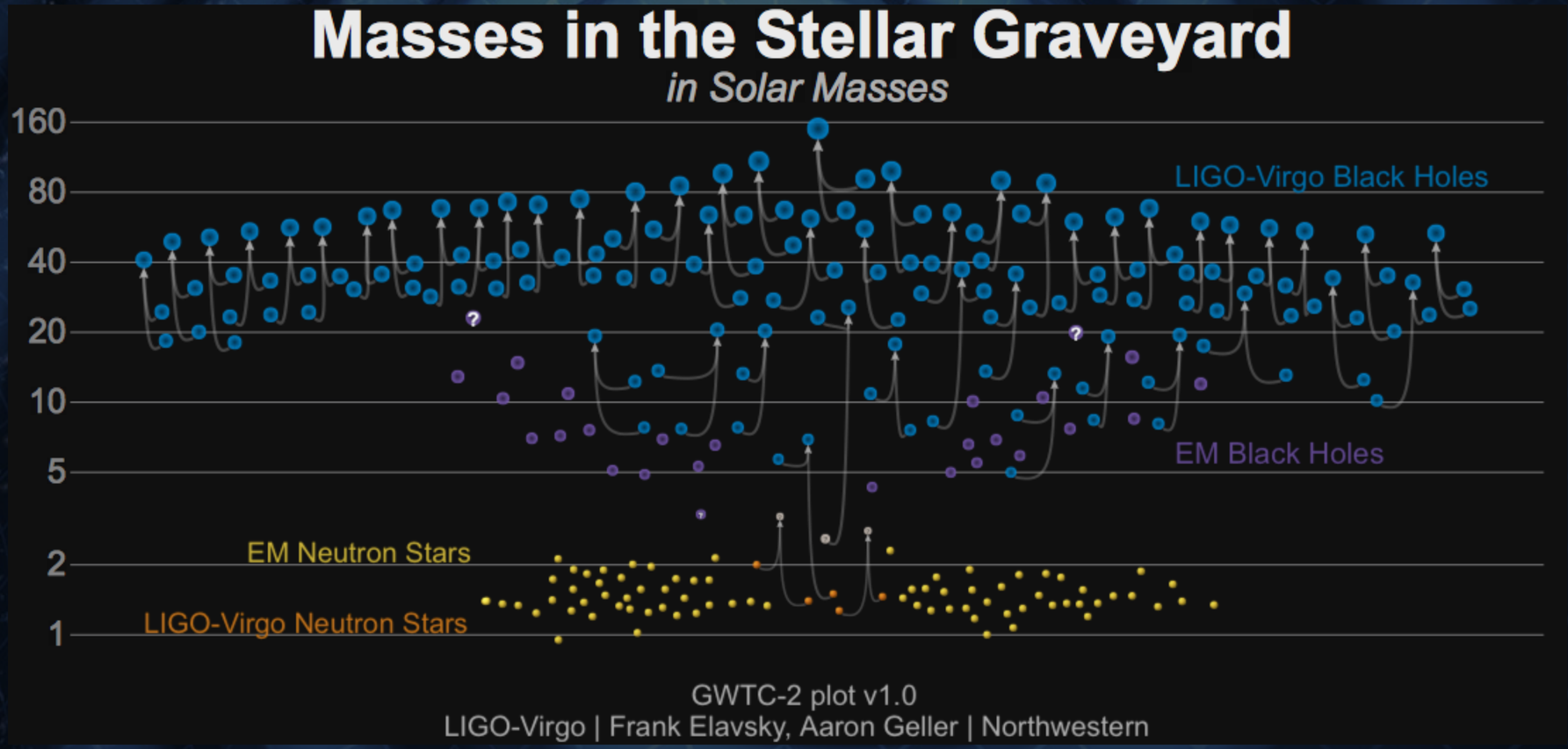
Some scientific results

- First detection of GW from **colliding black holes** (Phys. Rev. Lett. 116 (2016) 061102)
- First detection of GW from **colliding neutron stars** (Phys. Rev. Lett. 119 (2017) 161101)
  - ✓ First joint GW and electromagnetic observation (Astrophys. J. Lett. 848 (2017) L12)

To date a total of **50 GW candidate events:**

- Mainly mergers of black holes
- Two 'mixed' neutron star-black hole systems
- Two binary neutron stars

(see Phys. Rev. X 9 (2019) 031040
And arXiv:2010.14527)



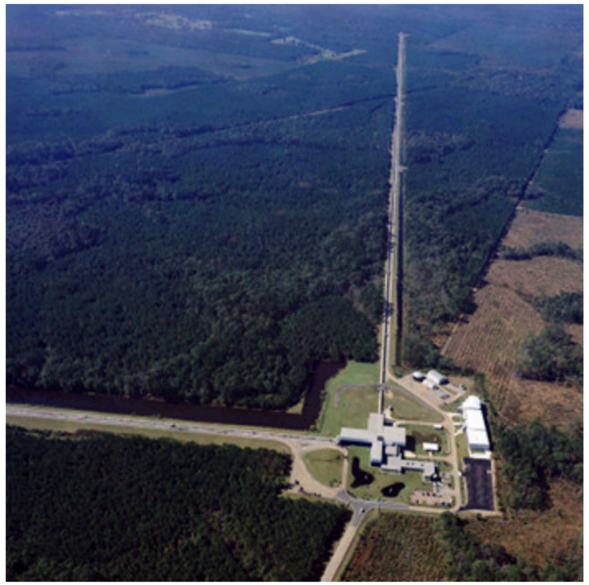
Gravitational Wave Open Science Center

Data Software Online Tools About GWOSC

The Gravitational Wave Open Science Center provides data from gravitational-wave observatories, along with access to tutorials and software tools.

LIGO Hanford Observatory, Washington

(Credits: C. Gray)



LIGO Livingston Observatory, Louisiana

(Credits: J. Giaime)

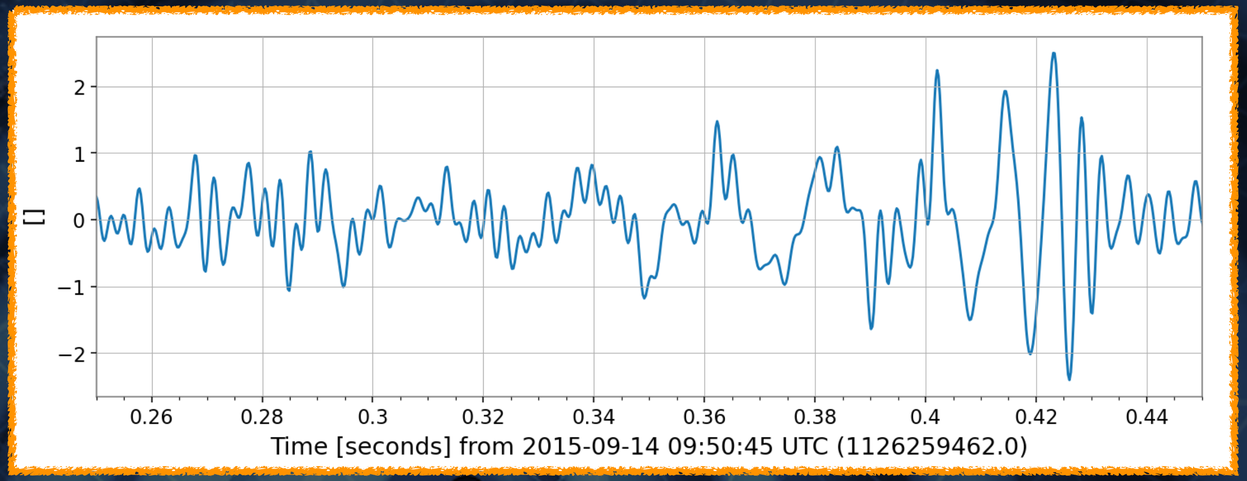
Virgo detector, Italy

(Credits: Virgo Collaboration)

https://www.gw-openscience.org/

Available data products

Strain Data

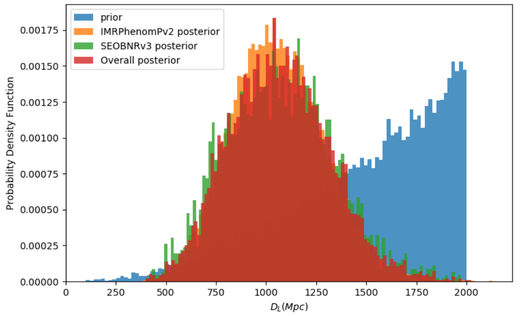


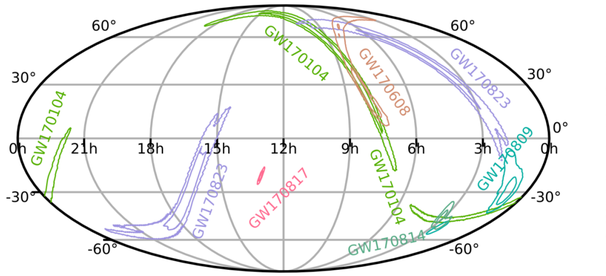
Segments (Timelines)

Start	Stop	Duration
1164559440	1164559654	214
1164560599	1164561392	793
1164562093	1164569775	7682

Analysis Results

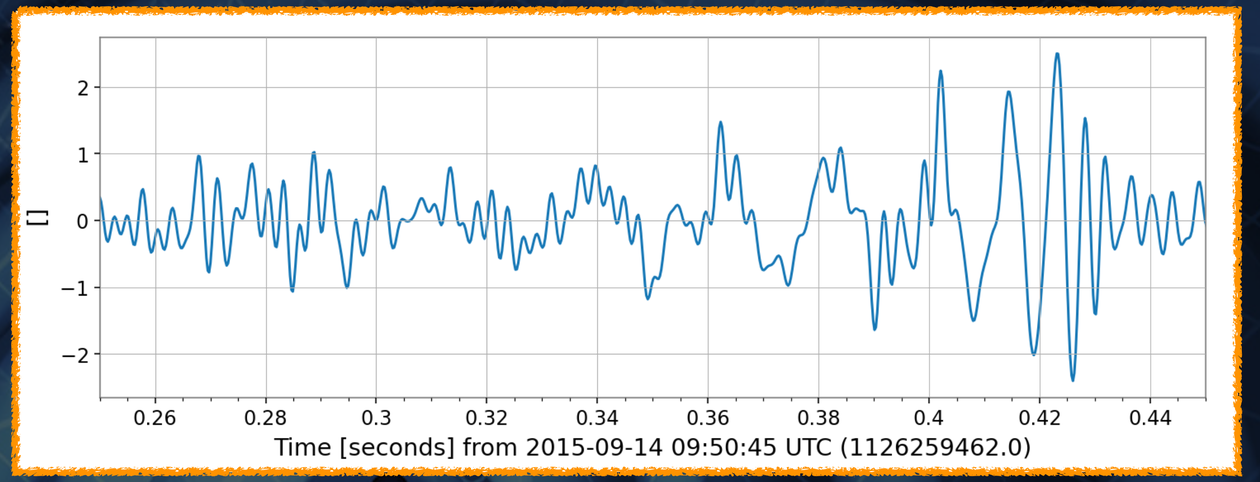
(mainly related to events or event catalogs)



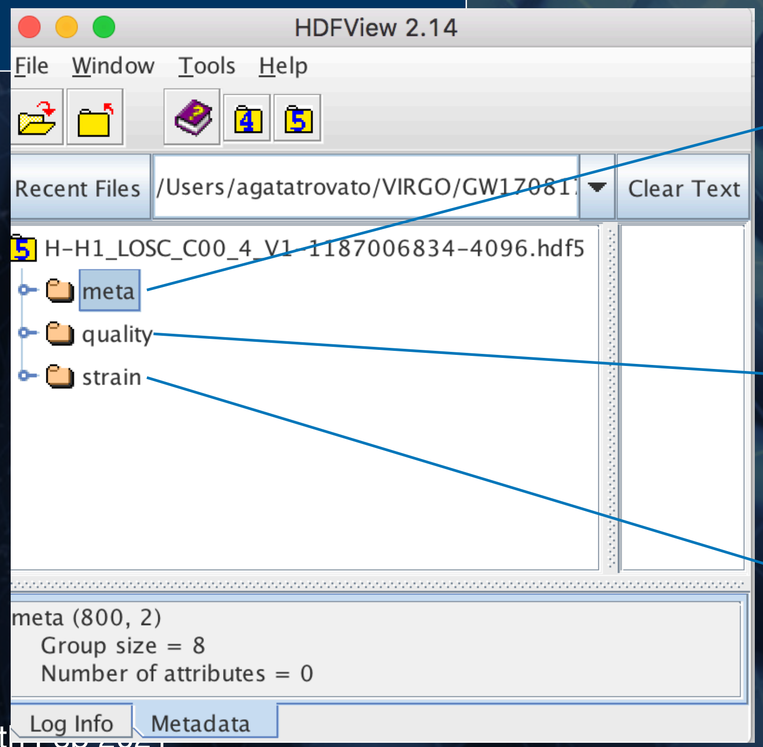


LIGO/Virgo data in GWOSC files

- LIGO/Virgo data: strain, data quality and hardware injections
- LIGO/Virgo data are arranged in files provided in different formats:
  - HDF5: easily readable in python, MATLAB, C/C++, and IDL
  - Frame format (.gwf)
  - Text file



You can use HDFView to quickly see what is inside the file



Meta-data for the file. This is basic information such as the GPS times covered, which instrument, etc.

Refers to data quality. The main item here is a 1 Hz time series describing the data quality for each second of data.

Strain data from the interferometer. In some sense, this is "the data", the main measurement performed by LIGO/Virgo.

GWOSC releases

- Two different types of data release:
  - **Gravitational wave data surrounding discoveries**
  - **Data taken during a whole observation run**

For details on LVC open data see: SoftwareX 13 (2021) 100658

Data	Date of release
GW150914: First Observed BBH*	Feb 2016
GW170817: First Observed BNS**	Oct 2017 (about 60 days after the discovery)
First Observing run, **O1** (Sep 2015 - Jan 2016)	Jan 2018
GWTC-1 Catalog (O1 + O2 detections)	Dec 2018
Second Observing run, **O2** (Nov 2016 - Aug 2017)	Feb 2019
GWTC-3 Catalog (O3a detections)	Oct 2020

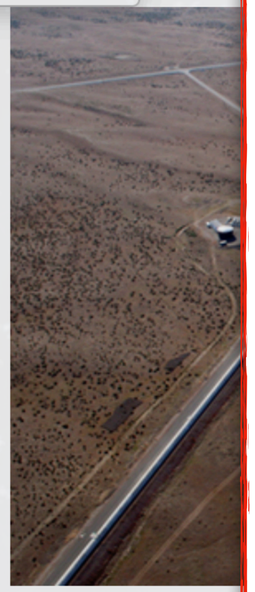
BBH* = Binary Black Hole BNS** = Binary Neutron Star

Finding GWOSC data

Gravitational Wave Open Science Center

Data | Software | Onl

- Strain Data
- Event Portal
- Timelines
- Auxiliary Channels
- Low Latency Alerts



LIGO Hanfor

Events and Catalogs

Event Portal

Large Data Sets

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

CVMFS Docs

Distributed filesystem that will allow you to mount the data local to your computer

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

~0.85 TB | ~3.4 TB

O2 Time Range: November 30, 2016 through August 25, 2017
Detectors: H1, L1 and V1

4 kHz Data | 16 kHz Data | Documents

Timeline

O1 Data Release

~0.35 TB | ~1.4 TB

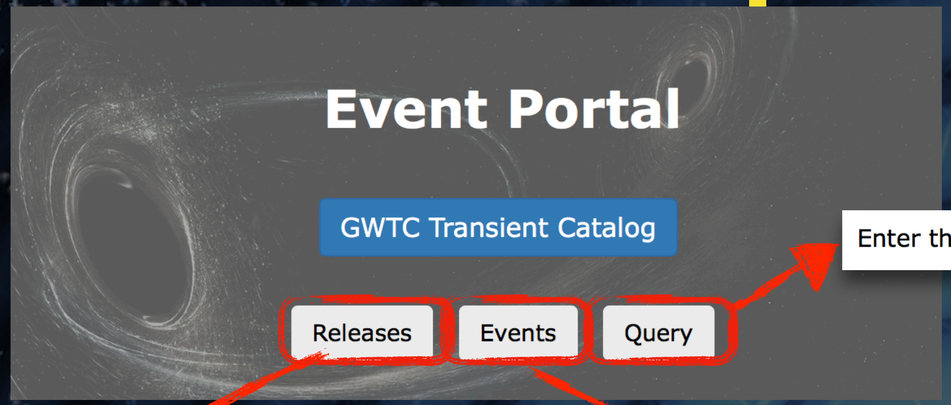
O1 Time Range: September 12, 2015 through January 19, 2016
Detectors: H1 and L1

4 kHz Data | 16 kHz Data | Documents

Timeline

Scrolling down you get the data for S5 and S6

Event portal



Enter the **name or partial name of the event**: (GPS ↔ UTC converter)

Release List

Release Name	Description
GWTC-1-confident	Confident detections from "GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs." Additional data products, including PE samples and skymaps, are linked from the documentation at https://doi.org/10.7935/82H3-HH23
GWTC-1-marginal	Marginal triggers from "GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs." Additional data products are linked from the documentation at https://doi.org/10.7935/82H3-HH23
GWTC-2	Events from the O3a observation run of LIGO and Virgo, as described in the GWTC-2 catalog paper. These events are also included in a cumulative list of all GWTC events published to date. Details and additional data products are linked from the documentation page.
Initial_LIGO_Virgo	Event data releases from initial LIGO and Virgo, 2005 - 2010. No astrophysical detections were made during this period.
O1_O2-Preliminary	Notable events in O1 and O2 initially published before the GWTC-1 catalog. These data releases may contain preliminary versions of data quality segments and calibration. For additional documentation released at the time of publication, see the "reference" link for each event. Updated information for these events may be found in the GWTC-1 catalog.
O3_Discovery_Papers	Notable events in O3 initially published outside of main catalogs. Associated data releases may contain preliminary versions of data quality segments and calibration. See documentation page for additional notes.

Name	Version	Release	GPS ↓	Mass 1 ($M_\odot$)	Mass 2 ($M_\odot$)	Network SNR	Distance (Mpc)
GW190930_133541	v1	GWTC-2	1253885759.2	$12.3^{+12.5}_{-2.3}$	$7.8^{+1.7}_{-3.3}$	9.8	780^{+370}_{-330}
GW190929_012149	v1	GWTC-2	1253755327.5	$64.7^{+22.4}_{-18.9}$	$25.7^{+14.4}_{-9.7}$	9.9	3680^{+2980}_{-1680}
GW190924_021846	v1	GWTC-2	1253326744.8	$8.8^{+7.0}_{-2.0}$	$5.0^{+1.3}_{-1.9}$	13.2	570^{+220}_{-220}
GW190915_235702	v1	GWTC-2	1252627040.7	$34.9^{+9.5}_{-6.2}$	$24.4^{+5.5}_{-6.0}$	13.1	1700^{+710}_{-640}
GW190910_112807	v1	GWTC-2	1252150105.3	$43.5^{+7.6}_{-6.2}$	$35.1^{+6.3}_{-7.0}$	13.4	1570^{+1070}_{-640}
GW190909_114149	v1	GWTC-2	1252064527.7	$43.2^{+50.7}_{-12.2}$	$27.6^{+13.0}_{-10.9}$	8.5	4770^{+3700}_{-2660}
GW190828_065509	v1	GWTC-2	1251010527.9	$23.8^{+7.2}_{-7.0}$	$10.2^{+3.5}_{-2.1}$	11.1	1660^{+630}_{-610}
GW190828_063405	v1	GWTC-2	1251009263.8	$31.8^{+5.8}_{-3.9}$	$25.9^{+4.4}_{-4.6}$	16.0	2220^{+630}_{-950}
GW190814	v2	GWTC-2	1249852257.0	$23.2^{+1.1}_{-1.0}$	$2.6^{+8.0e-02}_{-9.0e-02}$	22.2	240^{+40}_{-50}
GW190814	v1	O3_Discovery_Papers	1249852257.0	$23.2^{+1.1}_{-1.0}$	$2.59^{+0.08}_{-0.09}$	$25.0^{+0.1}_{-0.2}$	241^{+41}_{-45}
GW190803_022701	v1	GWTC-2	1248834439.9	$36.1^{+10.2}_{-6.7}$	$26.7^{+7.1}_{-7.6}$	8.6	3690^{+2040}_{-1690}
GW190731_140936	v1	GWTC-2	1248617394.6	$39.3^{+11.8}_{-8.2}$	$28.0^{+8.9}_{-8.4}$	8.5	3970^{+2560}_{-2070}
GW190728_064510	v1	GWTC-2	1248331528.5	$12.2^{+7.1}_{-2.2}$	$8.1^{+1.7}_{-2.6}$	13.6	890^{+250}_{-370}

Example of an event page

GW190412

Documentation

Version: v3

All Versions: v1 v2 v3

GPS: 1239082262.2

UTC Time: 2019-04-12 05:30

Release: GWTC-2

GraceDB: S190412m

GCN: Notices • Circulars

Timeline: Query for segments

DOI: https://doi.org/10.7935/99gf-ax93

Data sourced from frame channels.

FrameChannels: [H1:DCS-CALIB_STRAIN_CLEAN_C01, L1:DCS-CALIB_STRAIN_CLEAN_C01, V1:Hrec_hoft_16384Hz]

Data sourced from frame types:

FrameTypes: [H1_HOFT_C01, L1_HOFT_C01, V1Online]

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

GstLAL Search Pipeline

show / hide parameters

Default SEARCH

GWTC-2 PE for GW190412

show / hide parameters

chi_eff	$0.25^{+0.08}_{-0.11}$
chirp_mass (M_sun)	$15.2^{+0.2}_{-0.2}$
chirp_mass_source (M_sun)	$13.3^{+0.4}_{-0.3}$
final_mass_source (M_sun)	$37.3^{+3.9}_{-3.9}$
luminosity_distance (Mpc)	740^{+140}_{-170}
mass_1_source (M_sun)	$30.0^{+4.7}_{-5.1}$
mass_2_source (M_sun)	$8.3^{+1.6}_{-0.9}$
redshift	$0.15^{+0.03}_{-0.03}$
total_mass_source (M_sun)	$38.4^{+3.8}_{-3.7}$

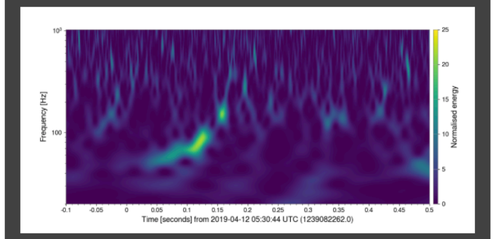
Source File

Posterior Samples DCC Entry

Skymap

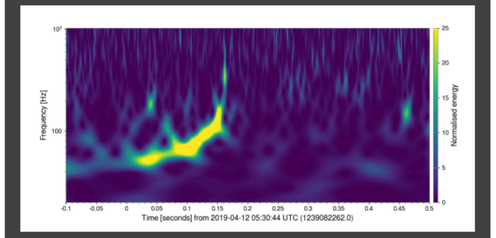
Default PE

H1 strain



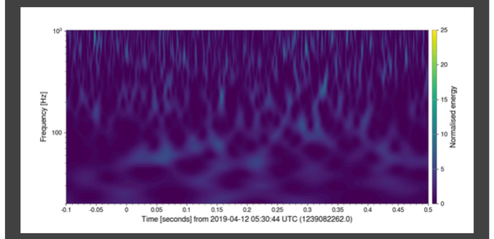
32sec • 16KHz: GWF HDF TXT
32sec • 4KHz: GWF HDF TXT
4096sec • 16KHz: GWF HDF TXT
4096sec • 4KHz: GWF HDF TXT

L1 strain



32sec • 16KHz: GWF HDF TXT
32sec • 4KHz: GWF HDF TXT
4096sec • 16KHz: GWF HDF TXT
4096sec • 4KHz: GWF HDF TXT

V1 strain

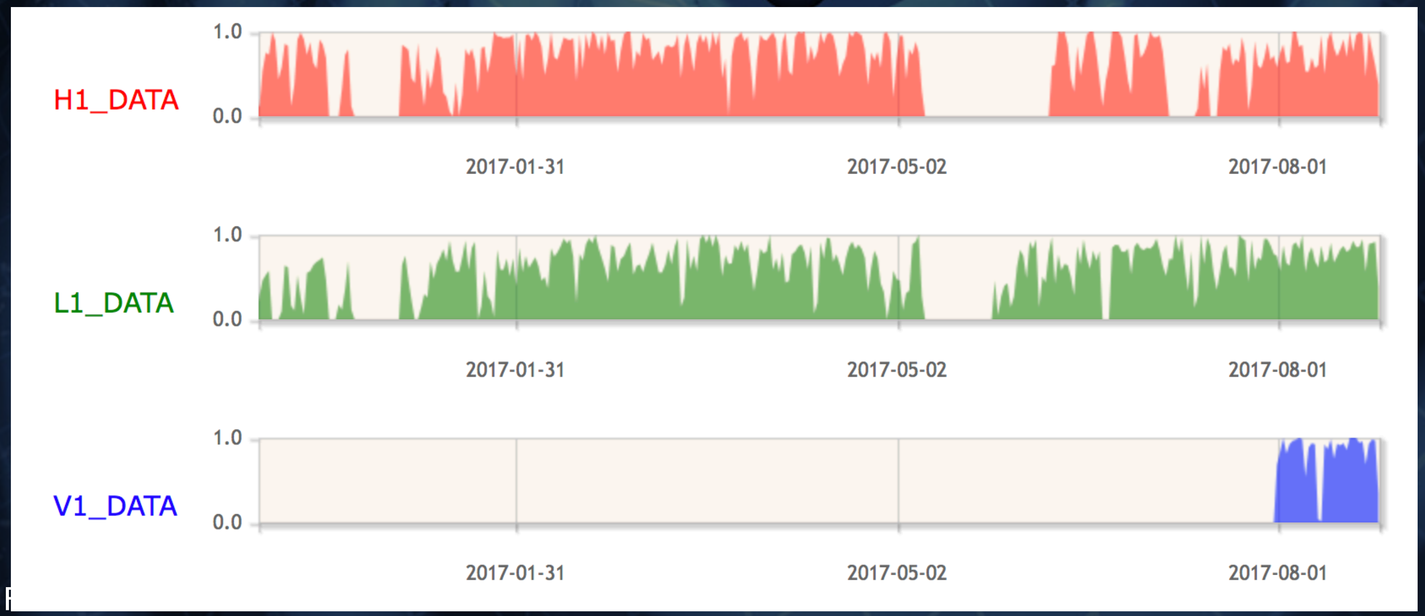


32sec • 16KHz: GWF HDF TXT
32sec • 4KHz: GWF HDF TXT
4096sec • 16KHz: GWF HDF TXT
4096sec • 4KHz: GWF HDF TXT

Segment Lists

- LIGO/Virgo data are not always 'on' (in science mode)
- Data quality may not meet basic requirements
- Consequence : GW data analysis is applied to data segments (different in each detector)
- The “Timeline” tool of the GWOSC website allows you to select segments that fulfill specific data quality checks in a time period that can be selected specifying GPS time and duration

Timelines for O2

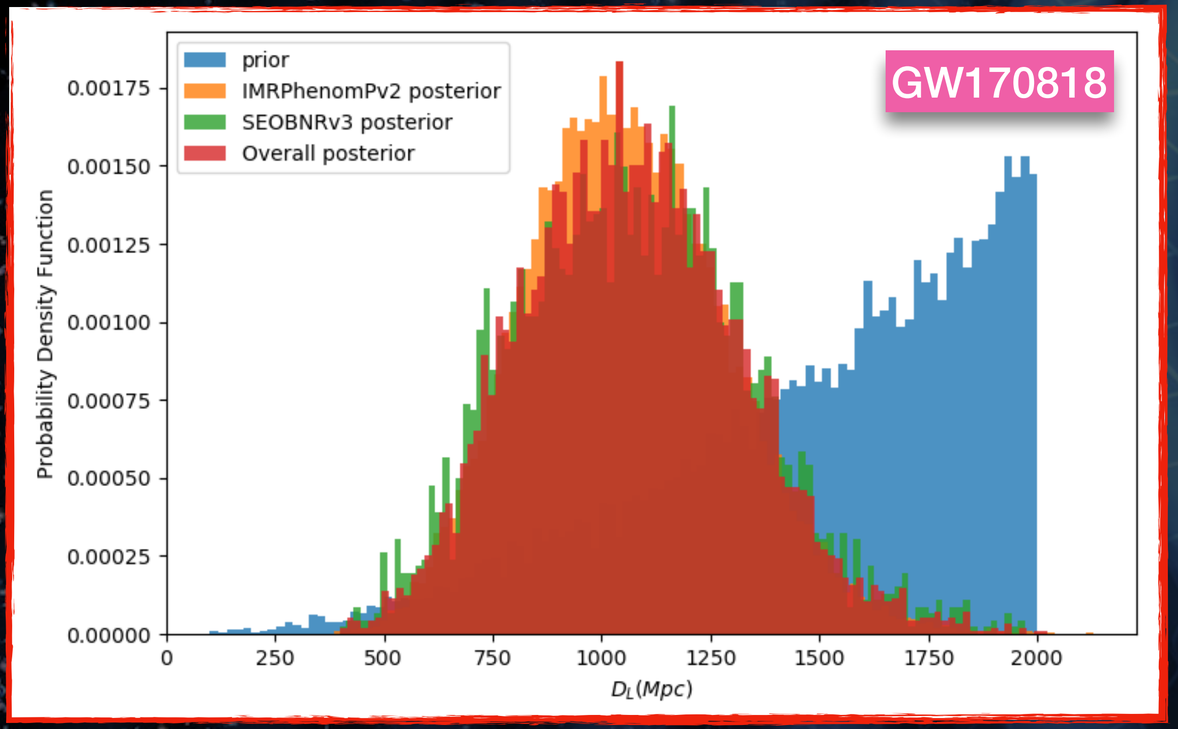


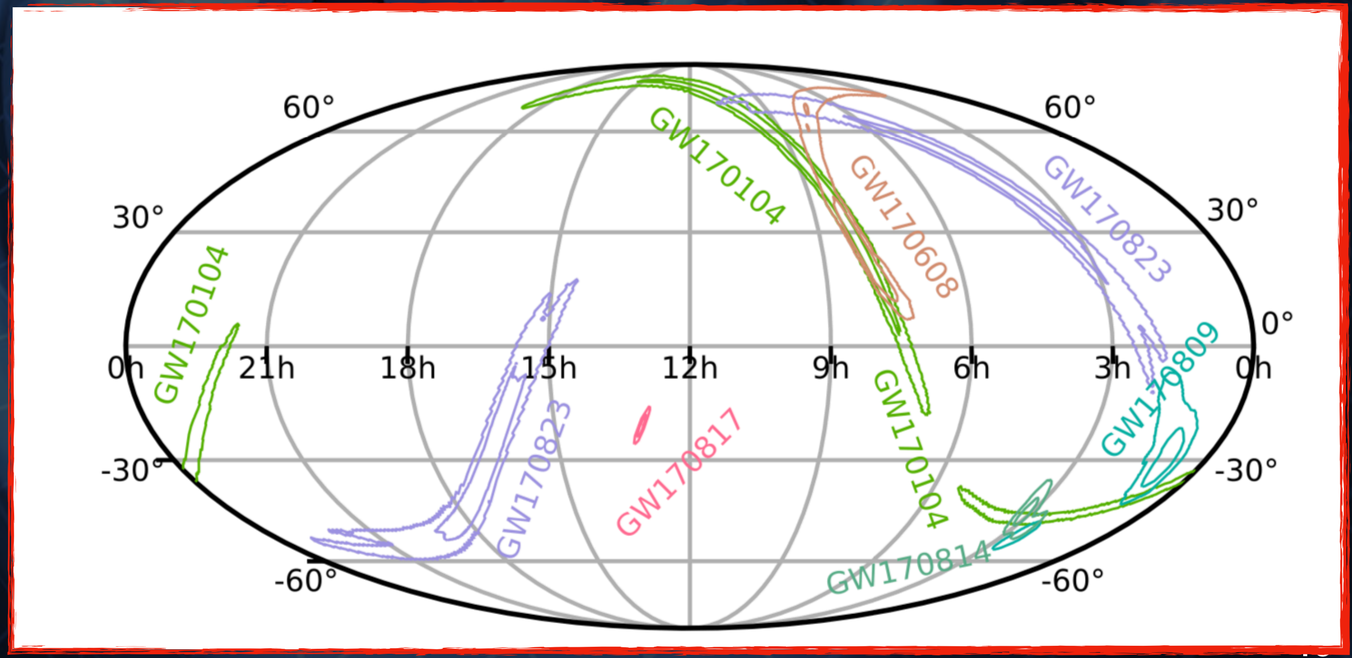
Data analysis results

- The event portal contains links to:
  - ✓ Posterior samples
  - ✓ Confidence intervals
  - ✓ Skymaps

Data Products and Publications — GWTC-2 documentation page

- **Catalog Paper and Figures:** P2000061
- **Strain Data:** Event Portal
- **Parameter Estimation Samples & Skymaps**: P2000223
- **Tests of General Relativity:** P2000091
- **Population Properties:** P2000077
- **Search Sensitivity**: P2000217
- **Glitch Models**: P2000289
- **Low-Latency Alerts**: GraceDB





Software for GW data

- Software for working with Gravitational Wave Data available to the public: https://www.gw-openscience.org/software/
- API on the GWOSC web site + python client (called “gwosc”)
- Part of the software developed by LIGO/Virgo and open-source

PyCBC

Free and open software to study gravitational waves.

ligo.skymap

The ligo.skymap package provides tools for reading, writing, generating, and visualizing gravitational-wave probability maps from LIGO and Virgo. It includes the rapid sky localization code BAYESTAR, tools for making sky maps from MCMC samples, observation planning utilities, and tools for making beautiful astronomical maps.

Bilby

Bilby: a user-friendly Bayesian inference library.

GstLAL

gstlal provides a suite of GStreamer elements that expose gravitational-wave data analysis tools from the LALSuite library for use in GStreamer signal-processing pipelines.

LALSuite

The LSC Algorithm Library Suite (LALSuite) is a collection of component packages, each of which is tagged, packaged, and released separately.

Tutorials and workshops

Gravitational Wave Open Data Workshop #4 (2021)

Remote workshop, May 10-14, 2021

Workshop web site

Upcoming workshop

Gravitational Wave Open Data Workshop #3 (2020)

Lecture videos and tutorials from 2020 workshop

Course Material

Gravitational Wave Open Data Workshop #2 (2019)

Lecture videos and tutorials from 2019 workshop

Course Material

Gravitational Wave Open Data Workshop #1 (2018)

Lecture videos and tutorials from 2018 workshop

Course Material

Recorded lectures

Day 1: May 26 - Recording

08:00 - Workshop Welcome
08:15 - Introduction to LIGO detectors: Gregg Harry (slides)
09:00 - Public LIGO/Virgo data: Jonah Kanner (slides)
09:30 - Coffee Break
09:45 - Data quality and GWpy: Marissa Walker (slides)
10:30 - Session end
--- Break ---
A hands-on session will follow lectures (see below)

Day 2: May 27 - Recording

08:00 - Introduction to CBC: Alan Weinstein (slides)
08:45 - Searches with PyCBC: Derek Davis (slides)
09:30 - Coffee Break
09:45 - Parameter estimation with bilby: Sylvia Biscoveanu (slides)
10:30 - Session end
--- Break ---
A hands-on session will follow lectures (see below)

Hands-sessions

Gravitational Wave Open Data Workshop #3

Tutorial 1.1: Discovering open data from GW observatories

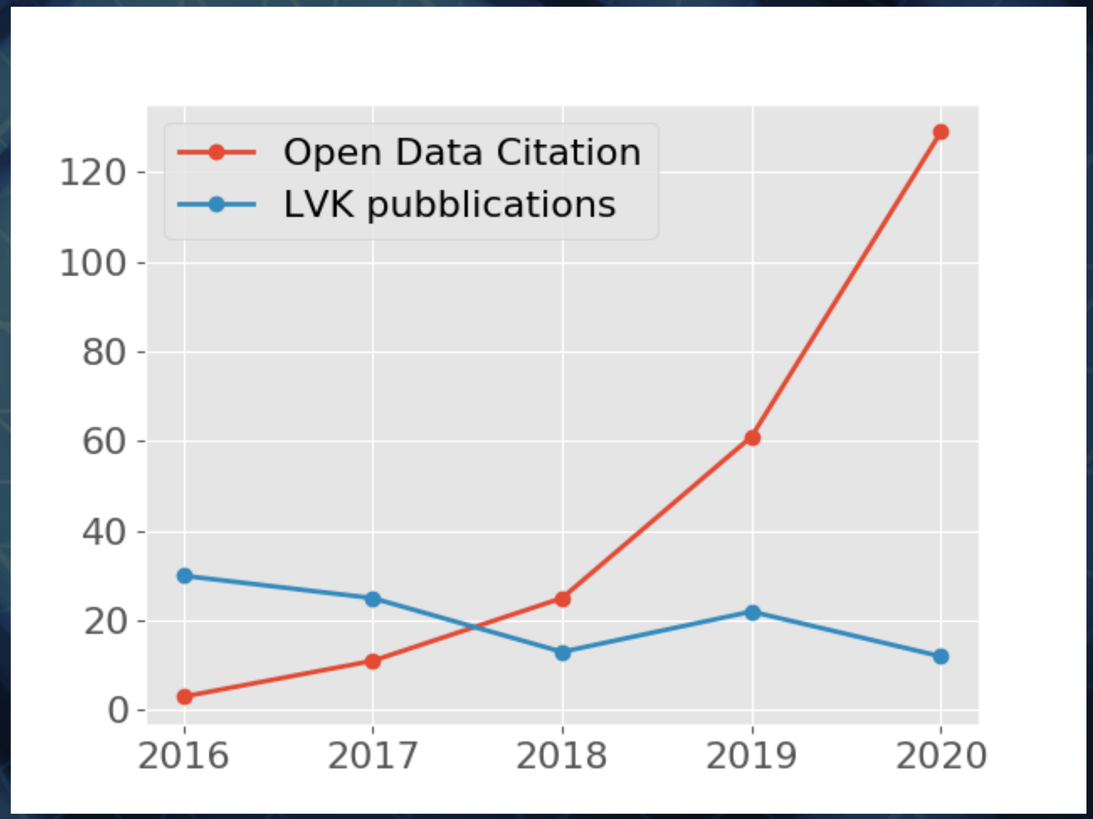
This notebook describes how to discover what data are available from the Gravitational-Wave Open Science Center (GWOSC).

Click this link to view this tutorial in Google Colaboratory

GWOSC Impact

- Examples of projects using GWOSC data: gw-openscience.org/projects/
  - ✓ Professional research, student projects, classroom activities, text books, art projects, workshops, training
  - ✓ Around 3000 visitors each month (unique IP) and thousands of strain file downloads

More than 230 published papers acknowledge use of GWOSC (INSPIRE-HEP)



New program for students

Learning Path

Teachers & Students

Objectives

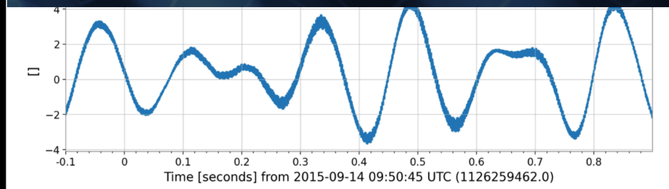
Step 1: Watch Introductory Video (1)

7 Minutes

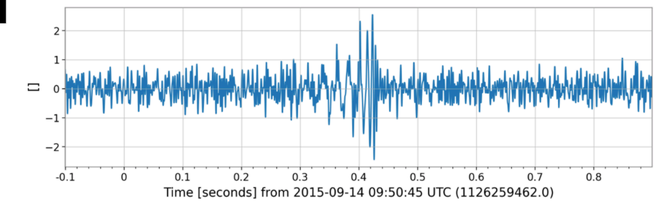
- How are gravitational waves created?
- How are gravitational waves measured?

Footnote: Construction of the KAGRA detector in Japan has been completed since the production of this video.

https://www.gw-openscience.org/path



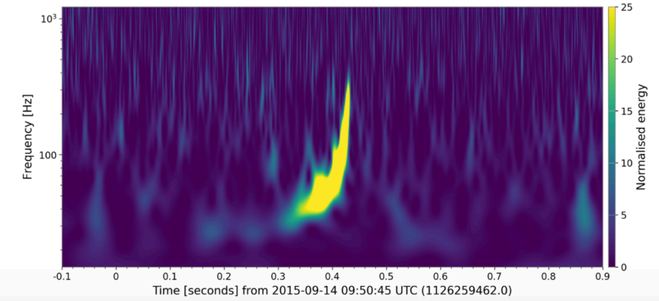
Whitened and Band-passed Data



Download Data as CSV File

See notes +

Q-transform



Detector

H1

Set Plot Parameters

Time Range (seconds)

1.00

0.10 8.00

Whitened and band-passed data

Whiten?

Band-pass frequency range (Hz)

30 400

10 2000

Q-tranform plot

Colorbar Max Energy

25

10 500

Q-value

5

5 120

Overview

- GWOSC is a successful open science project
  - ✓ A large and growing community of users
  - ✓ Data used in a good fraction of the publications related to GW astronomy

- Reproducibility of LVC results (see e. g. arXiv:2010.07244)
- Major upcoming data releases include: O3a (expected Apr 2021), catalog for O3b
- A wealth of science to come and to share!

A wealth of science to come and to share!