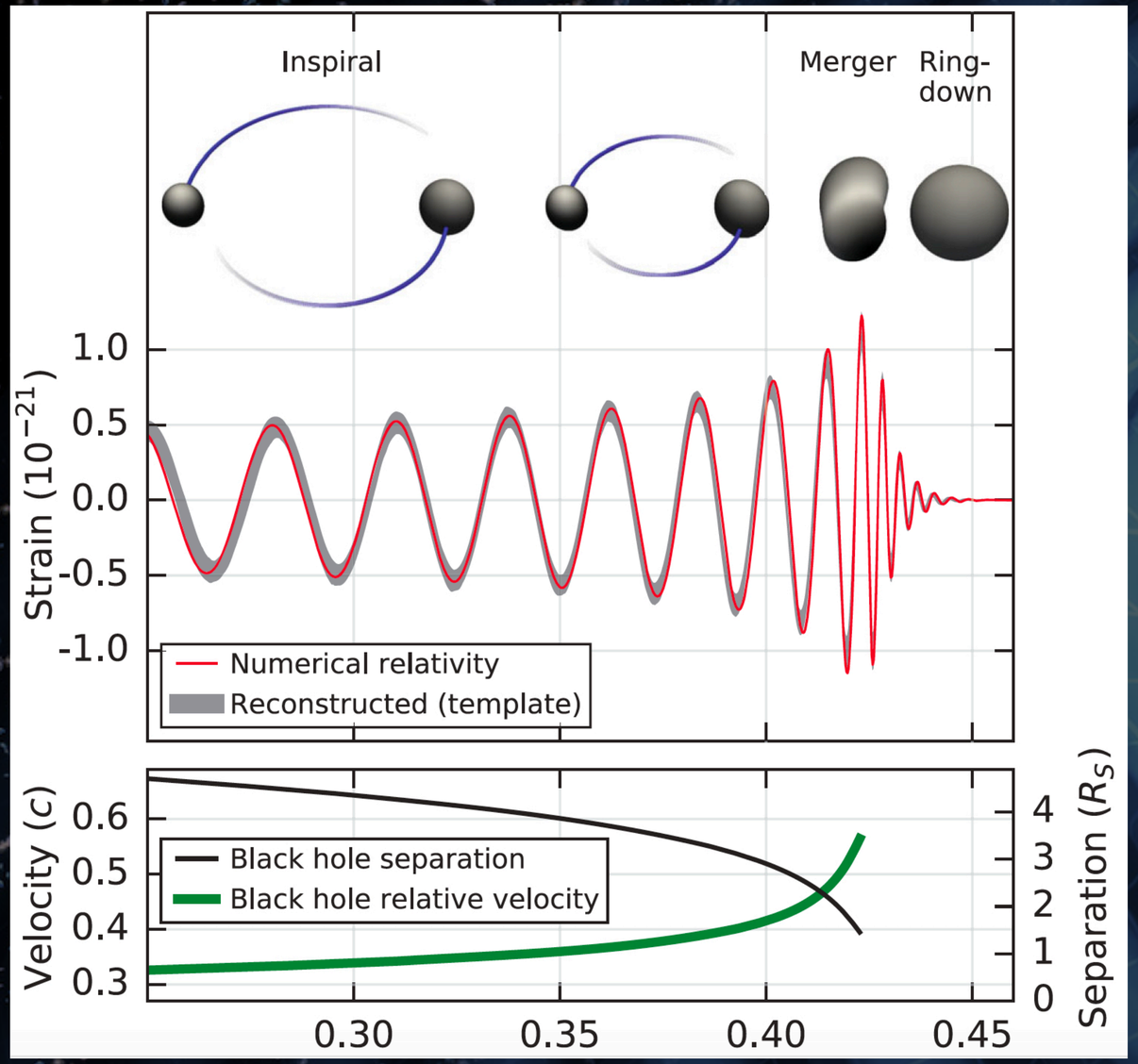
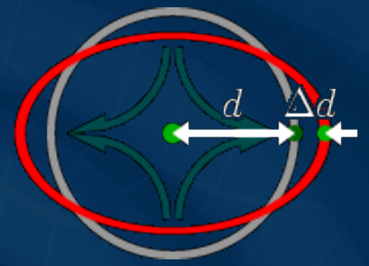
# Open Data from Virgo and LIGO Collaborations

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

# Gravitational waves



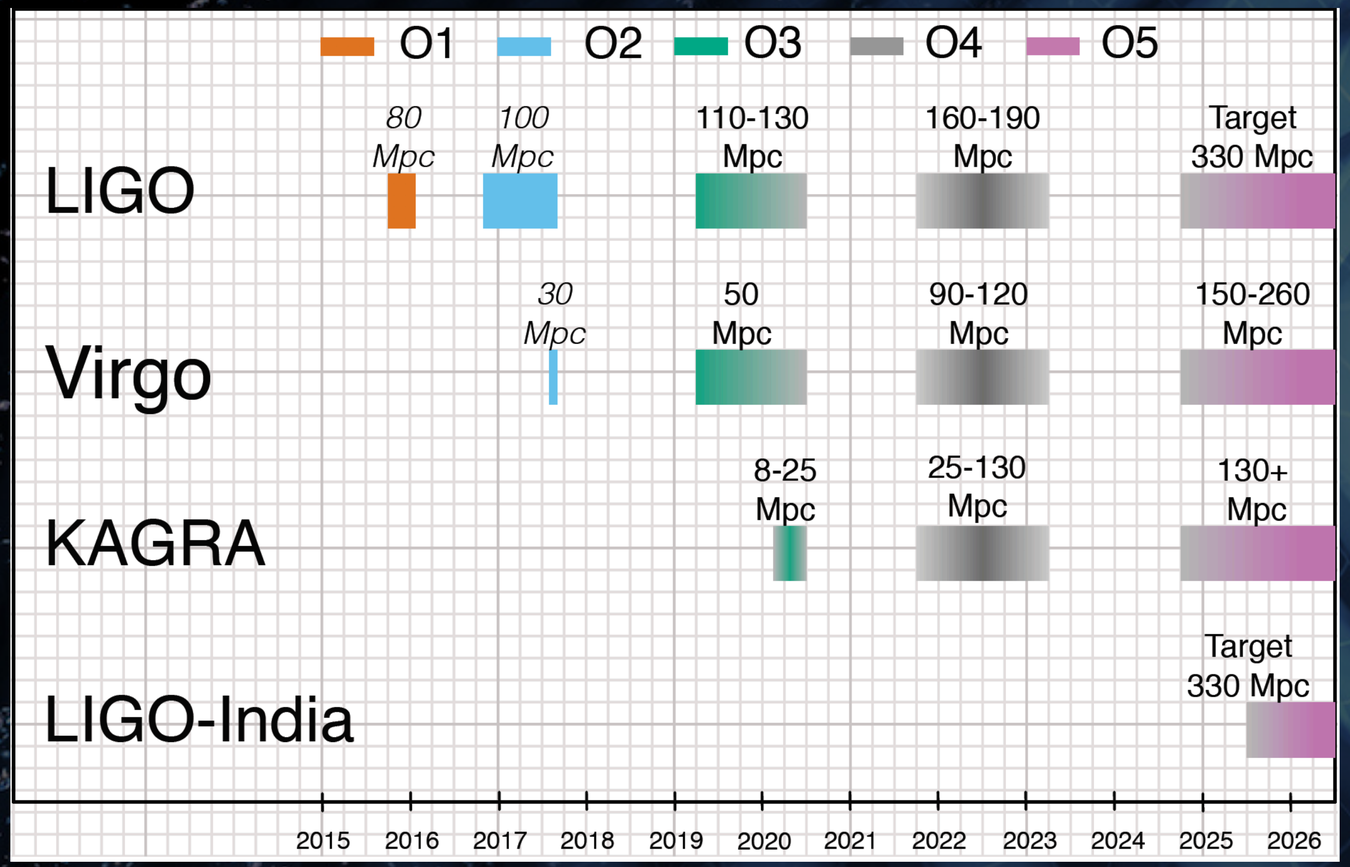

Reminder: strain



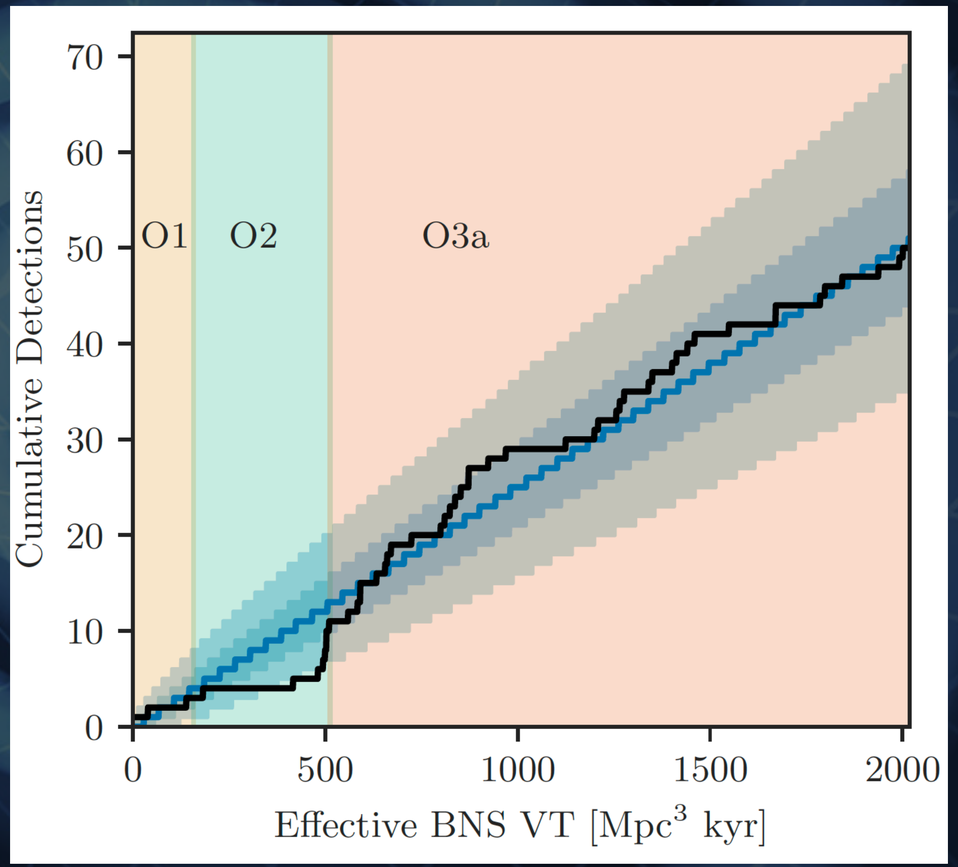

$$h = \frac{\Delta d}{d} = \frac{change\ in\ relative\ position}{separation}$$

# 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



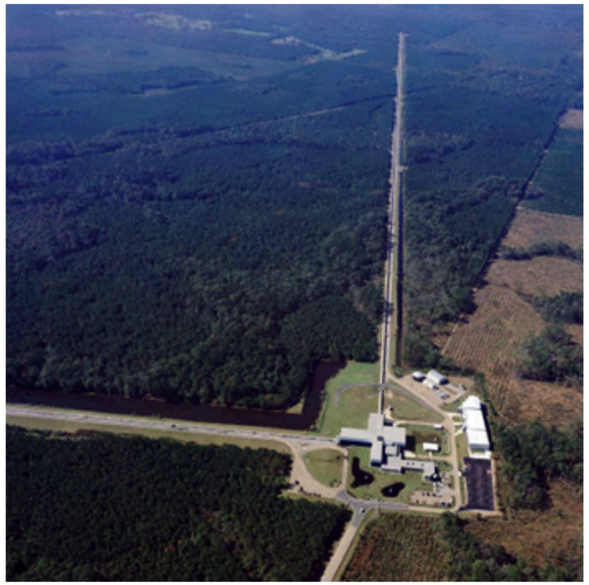
# Gravitational Wave Open Science Center

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)

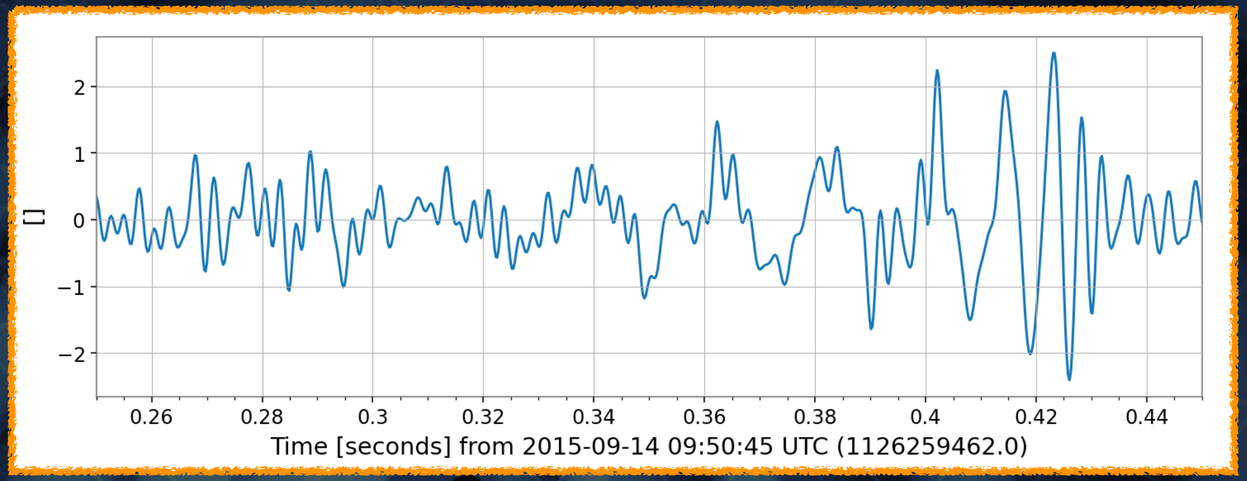
Virgo detector, Italy

(Credits: Virgo Collaboration)

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

# Available data products

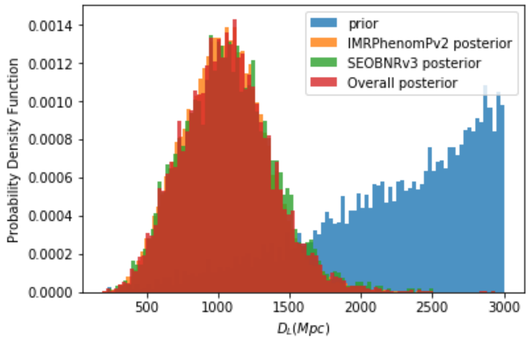
## Strain Data

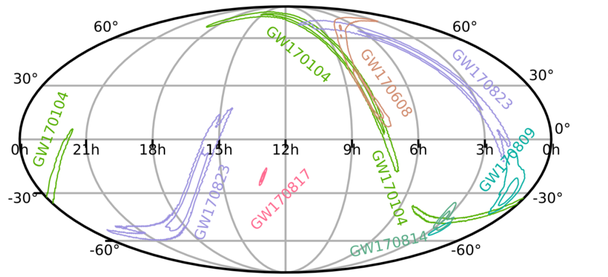



## Segments (Timelines)

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

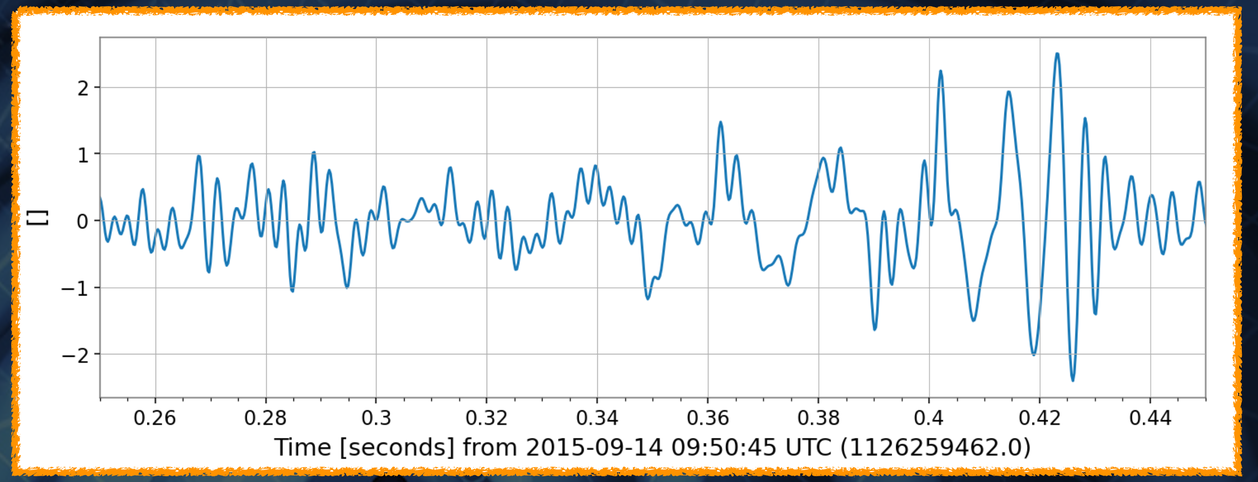
## Analysis Results



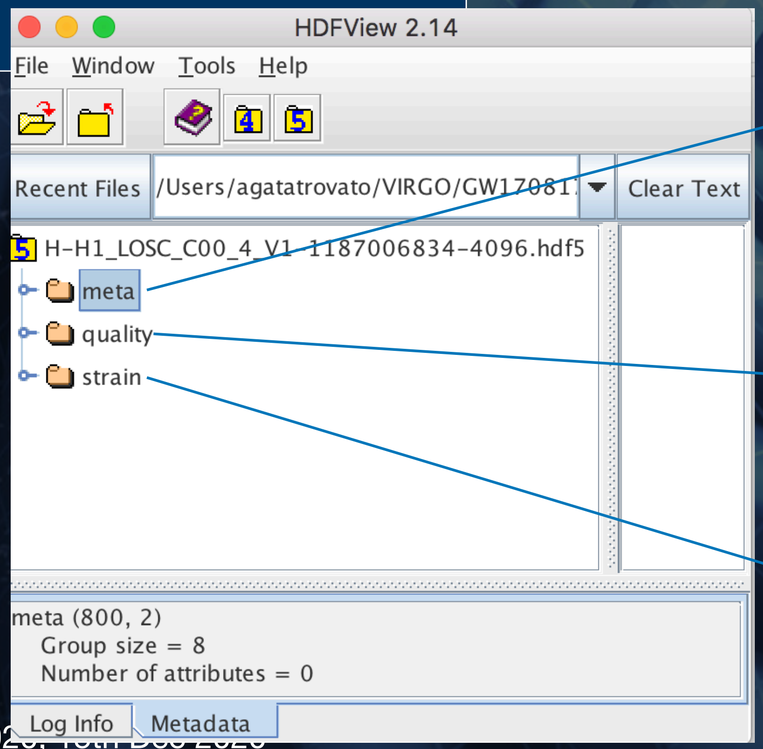



# LIGO/Virgo data

- 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**

| 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 |

# Finding GWOSC data

Gravitational Wave Open Science Center

Data | Software | Onl

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

## 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

**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.

Auxiliary Data

## O2 Data Release

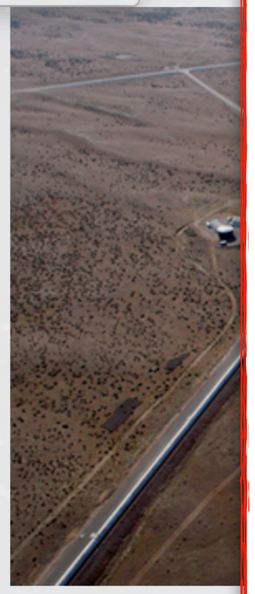
**O2 Time Range**: November 30, 2016 through August 25, 2017
**Detectors**: H1, L1 and V1

4 kHz Data | 16 kHz Data | Documents | Timeline

## O1 Data Release

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

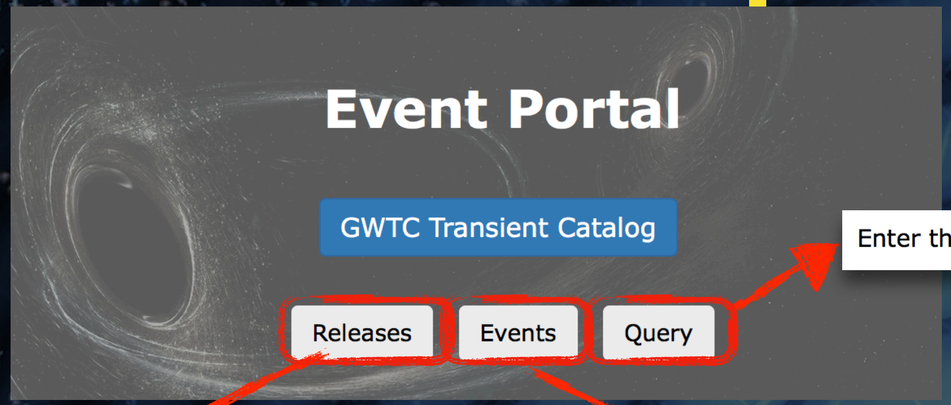
4 kHz Data | 16 kHz Data | Documents | Timeline



LIGO Hanfor

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 | $890^{+250}_{-370}$ |

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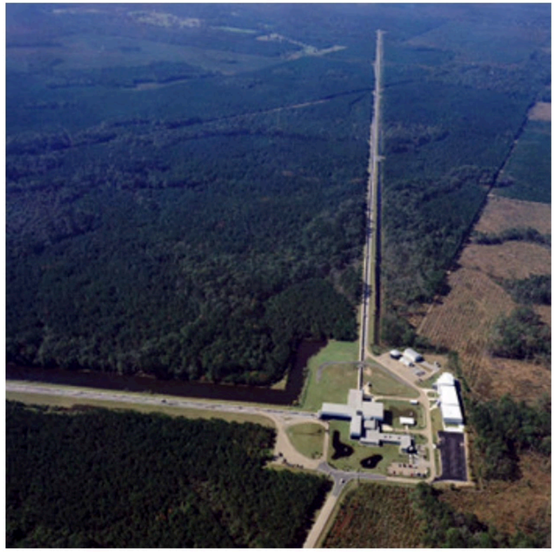

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(Credits: J. Giaime)

Virgo detector, Italy

(Credits: Virgo Collaboration)

**GWTC-2 data available!**

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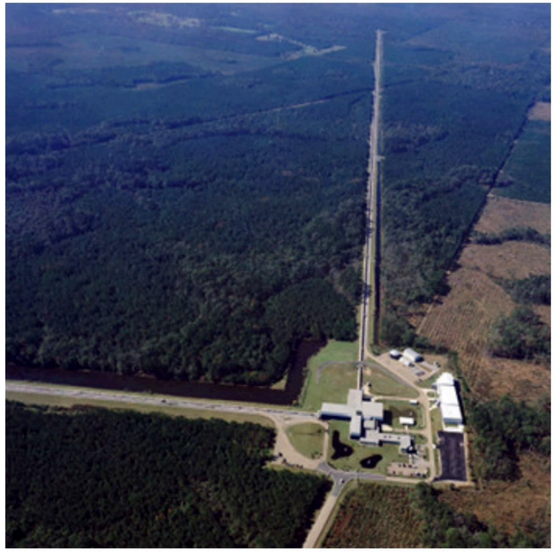

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(Credits: J. Giaime)

Virgo detector, Italy

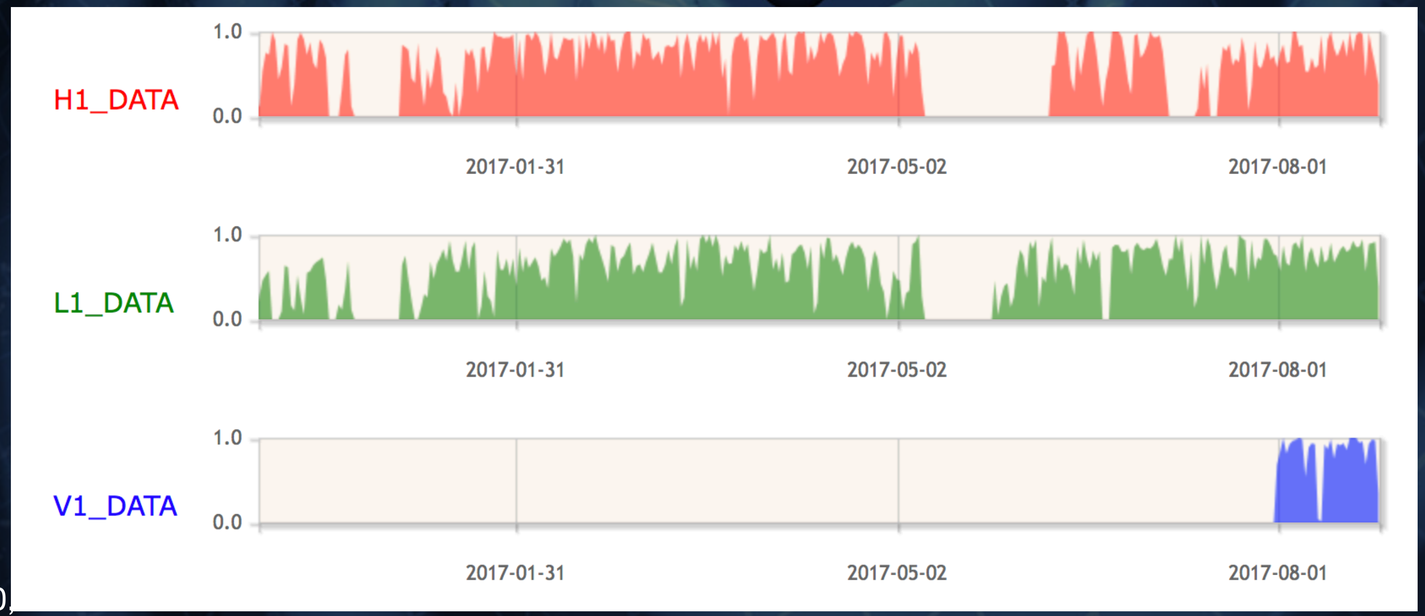
(Credits: Virgo Collaboration)

## GWTC-2 data available!

# 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



gw-openscience.org

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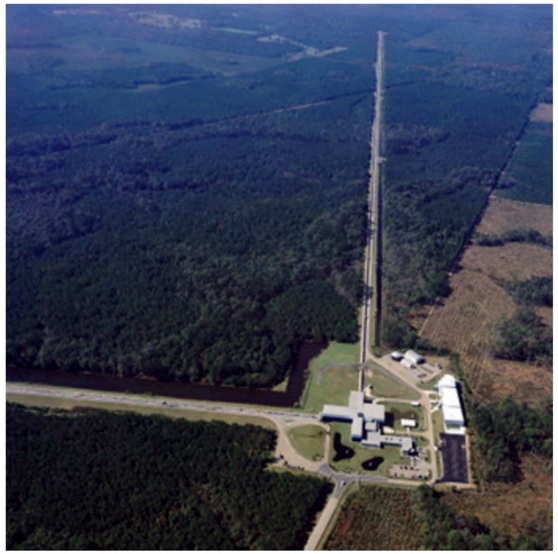


LIGO Livingston Observatory, Louisiana

(Credits: J. Giaime)

Virgo detector, Italy

(Credits: Virgo Collaboration)

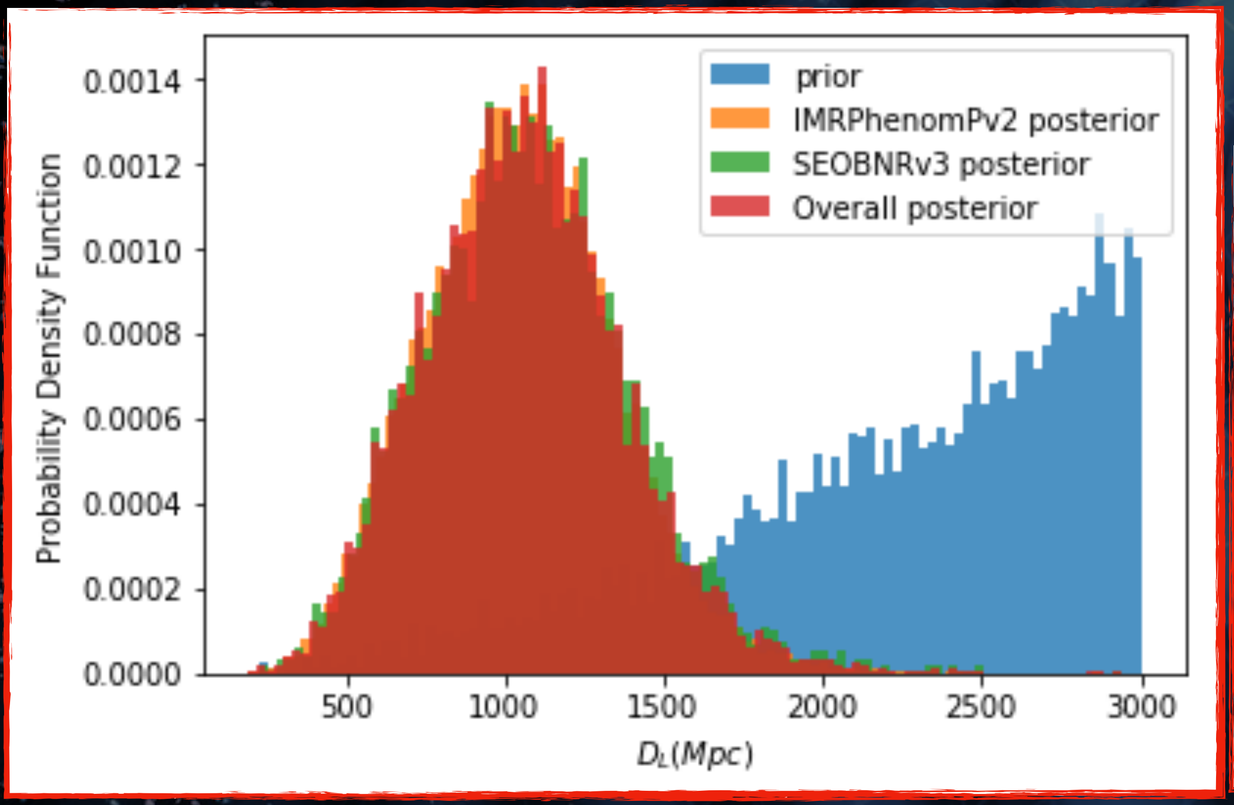
**GWTC-2 data available!**

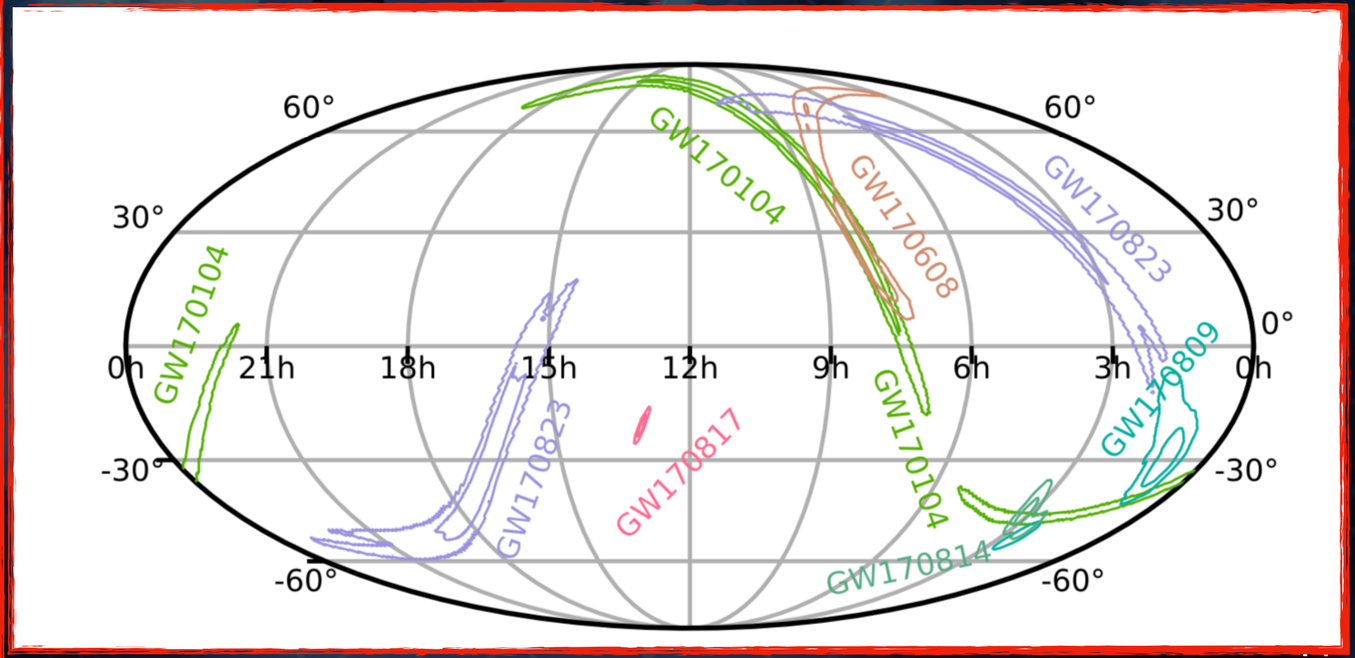
# Data analysis results

- 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/
- Part of the software developed by LIGO/Virgo and open-source

GWpy

a python package for gravitational-wave astrophysics.

PyCBC

Free and open software to study gravitational waves.

Bilby

Bilby: a user-friendly Bayesian inference library.

**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.

**LALSuite**

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

**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.

# Tutorials and workshops

## GW Open Data Workshops

**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

LIGO VIRGO

Gravitational Wave Open Data Workshop #3

Tutorial 1.1: Discovering open data from GW observatories

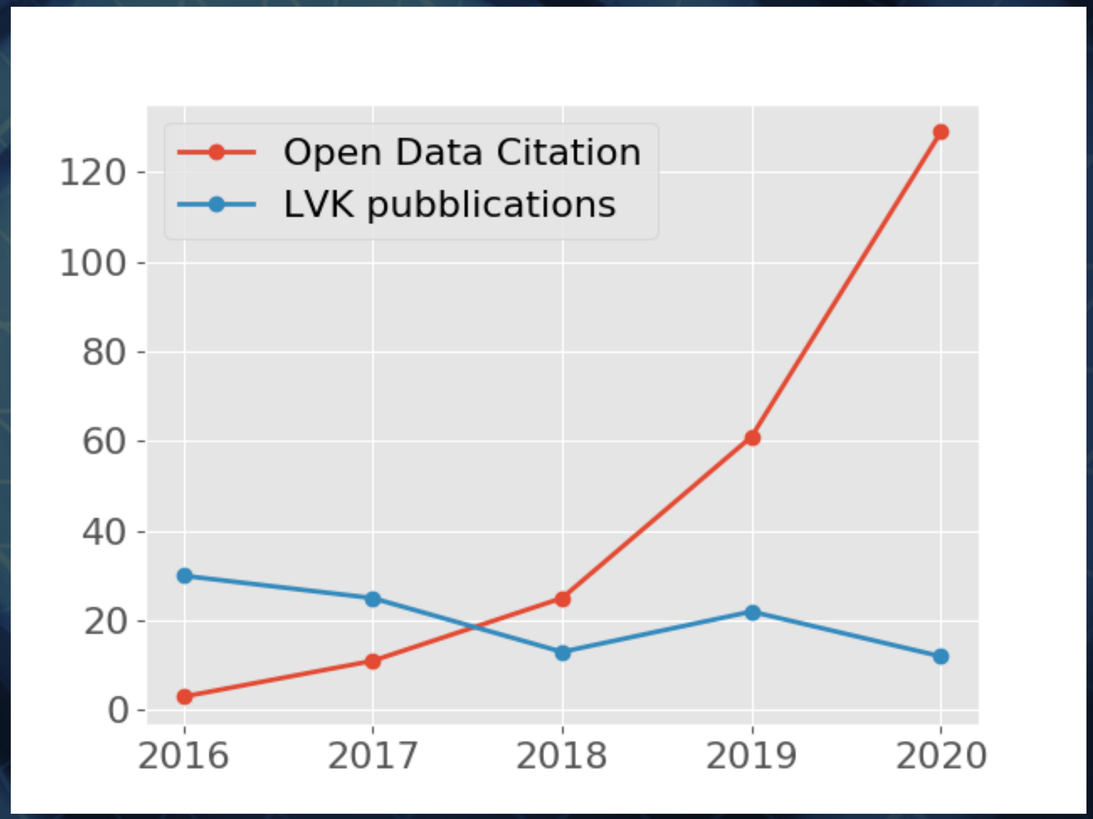
This notebook describes how to discover what data are available from the Gravitational-Wave Open Science Center (GWOSC).

Click this link to view this tutorial in Google Colaboratory

# GWOSC Impact

- Examples of projects using GWOSC data: https://www.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 200 published papers acknowledge use of GWOSC (INSPIRE-HEP)**



# New program for students

## Learning Path

### Teachers & Students

Objectives

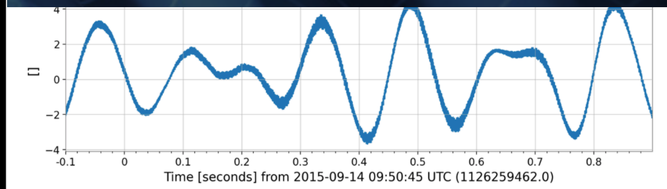
**Step 1: Watch Introductory Video (1)**

*7 Minutes*

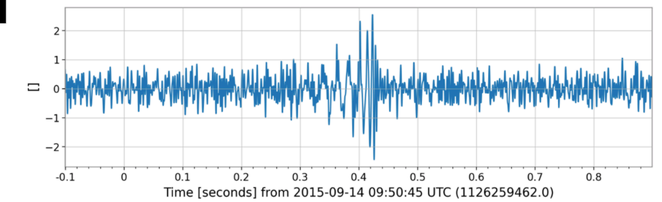
- How are gravitational waves created?
- How are gravitational waves measured?

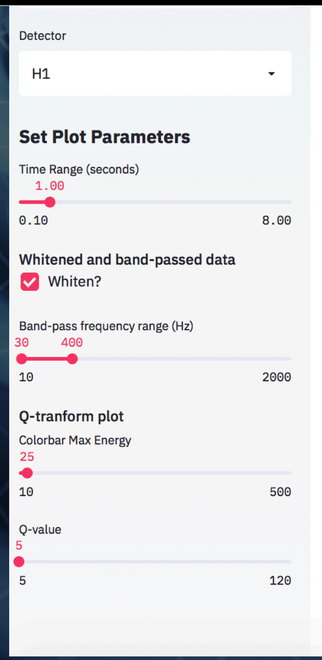

Footnote: Construction of the KAGRA detector in Japan has been completed since the production of this video.

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


Whitened and Band-passed Data

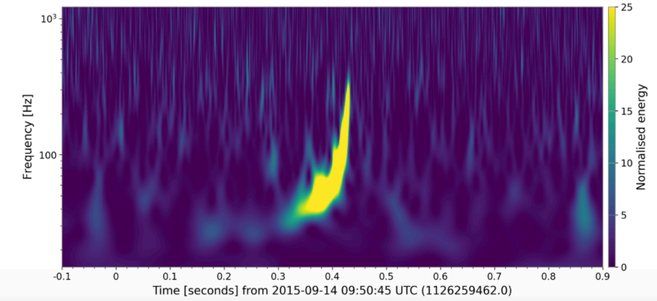



Download Data as CSV File

See notes +

Q-transform



# Overview

- GWOSC is a successful open science project


CERNCOURIER | Reporting on international high-energy physics

POLICY | FEATURE

**Preserving the legacy of particle physics**

11 March 2019

"Only days after they announced the first observation of gravitational waves, the LIGO and Virgo collaborations made public their data."

- Comply to FAIR standards
- O3a expected to be release in Apr 2021
  - ✓ Catalog for O3b in preparation
  - ✓ Few "special events" probably will be published before the next catalog
- A wealth of science to come and to share!

A wealth of science to come and to share!