

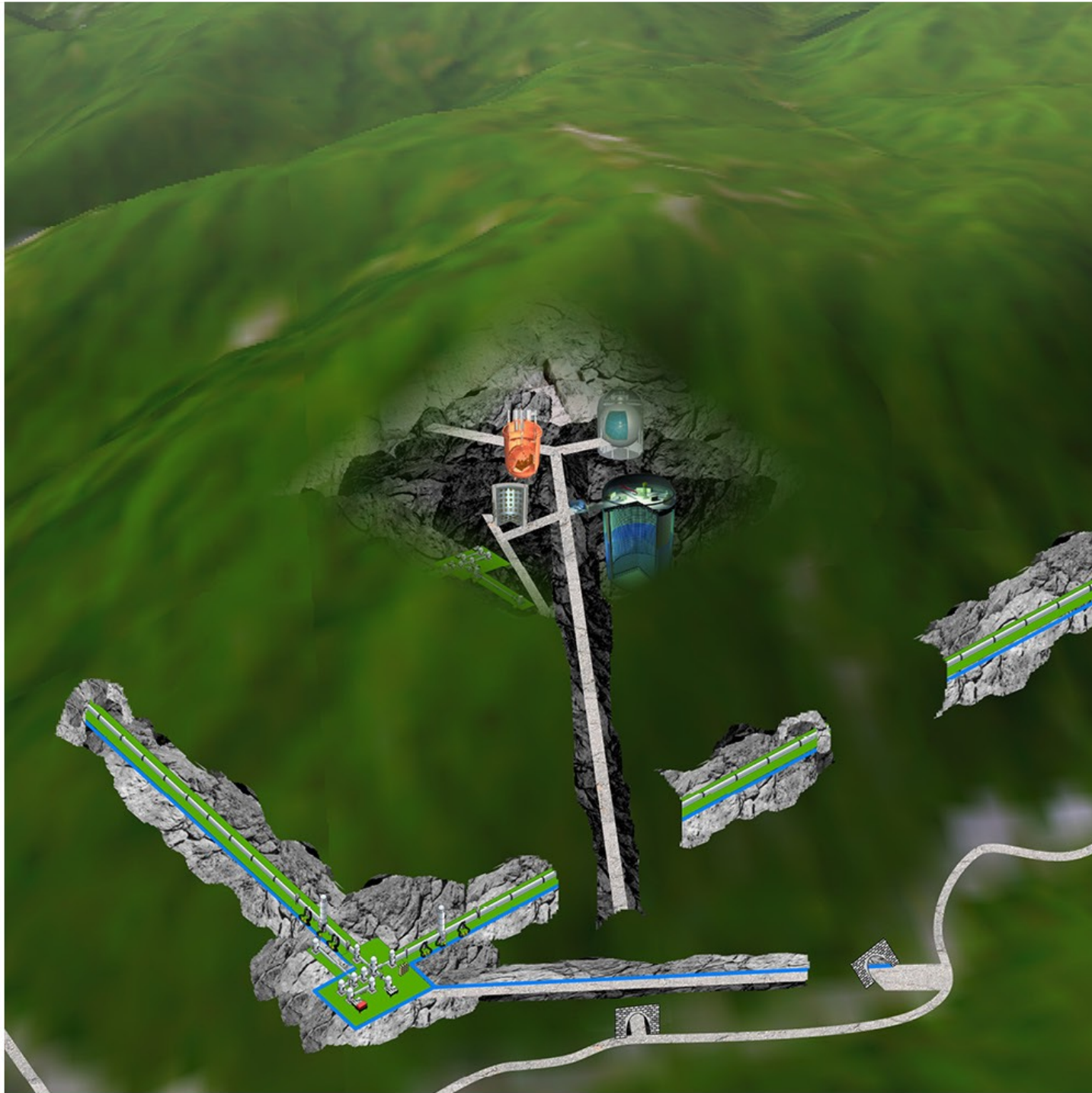
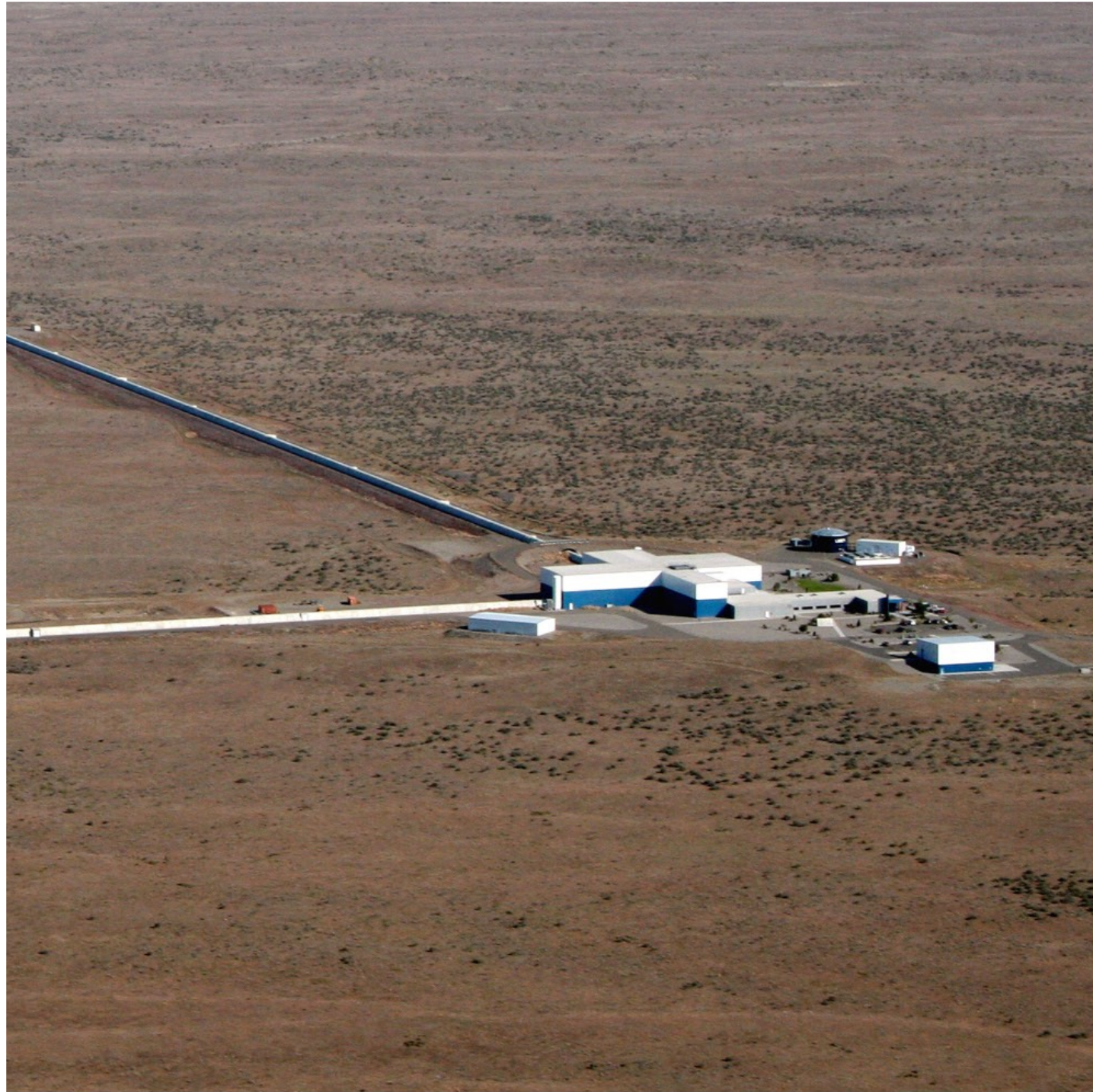
# LIGO-Virgo-KAGRA Open Data

Jonah Kanner

LIGO Lab, Caltech

April 18, 2024 | LIGO-G2400876-v3









# Gravitational Wave **Open Science Center**

Discover Gravitational-Wave Observatory Data,  
Tutorials, and Software Tools.

Explore Data

Learn

[gwosc.org](https://gwosc.org)

**Data**

**Documentation**

**Tutorials**

**Software**

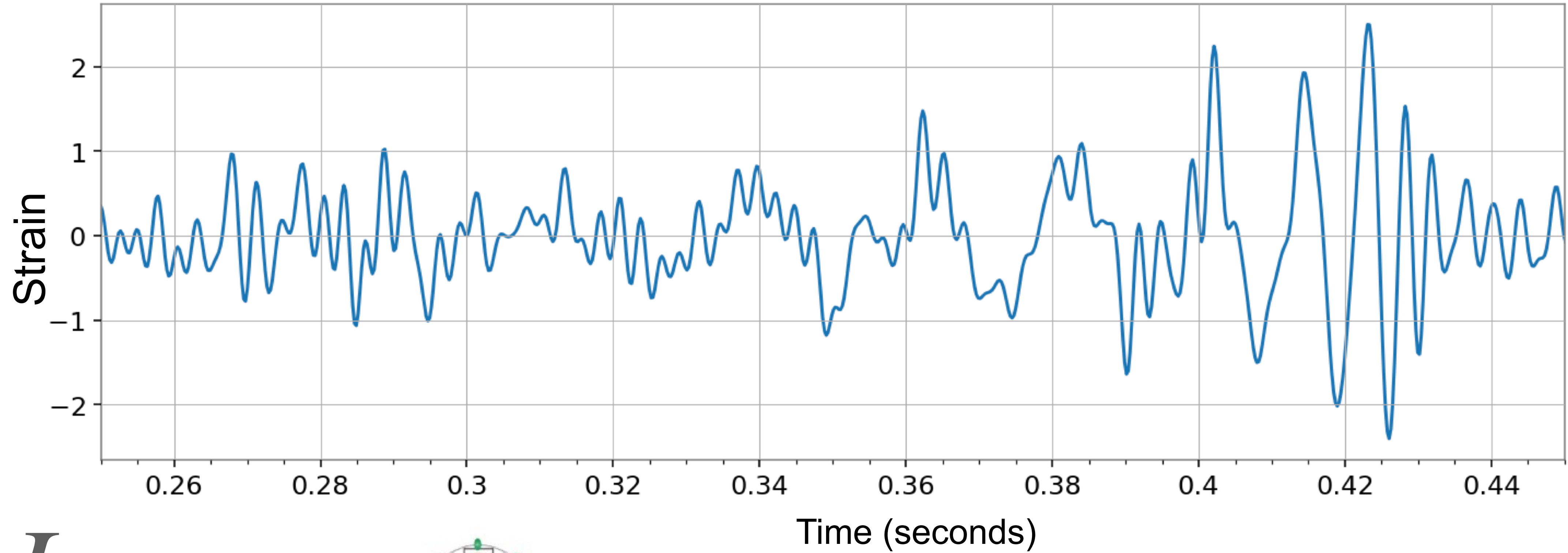
**Segment Lists**

**Web Apps**

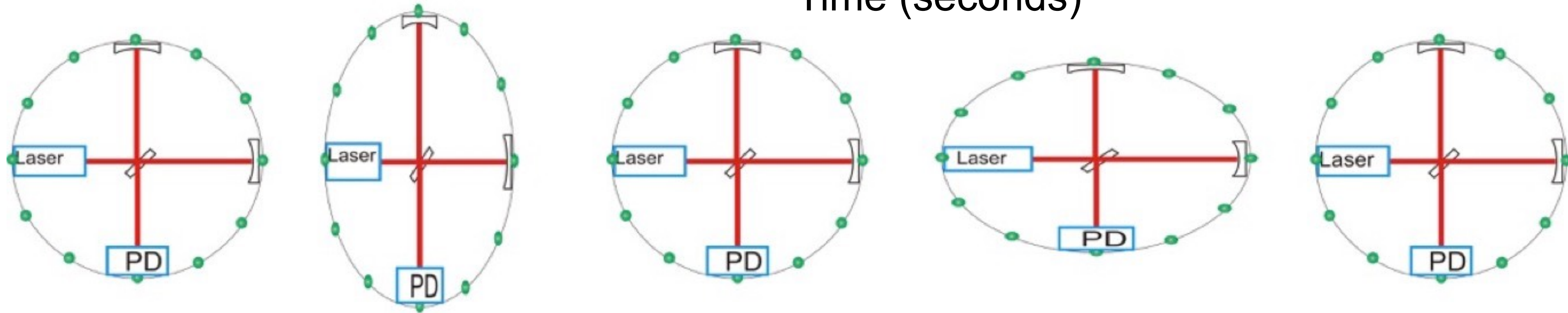
# Strain data



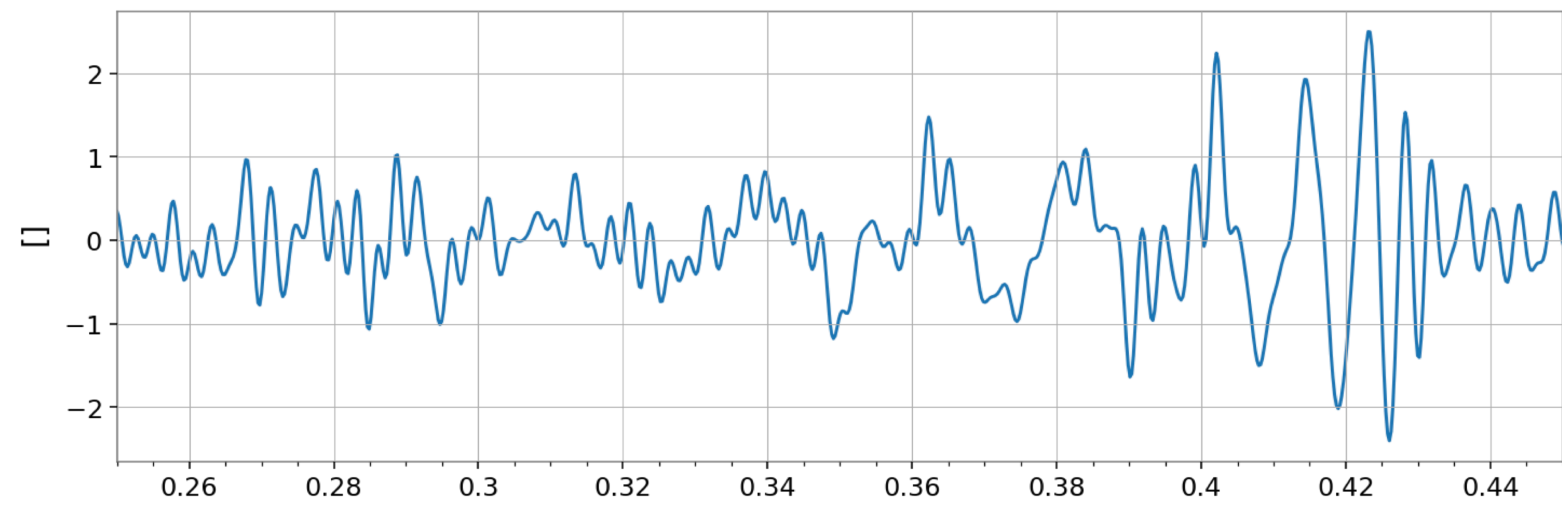
# Time Domain Strain Data



$$\frac{\Delta L}{L}$$







# Time Domain Strain Data

Time-series data

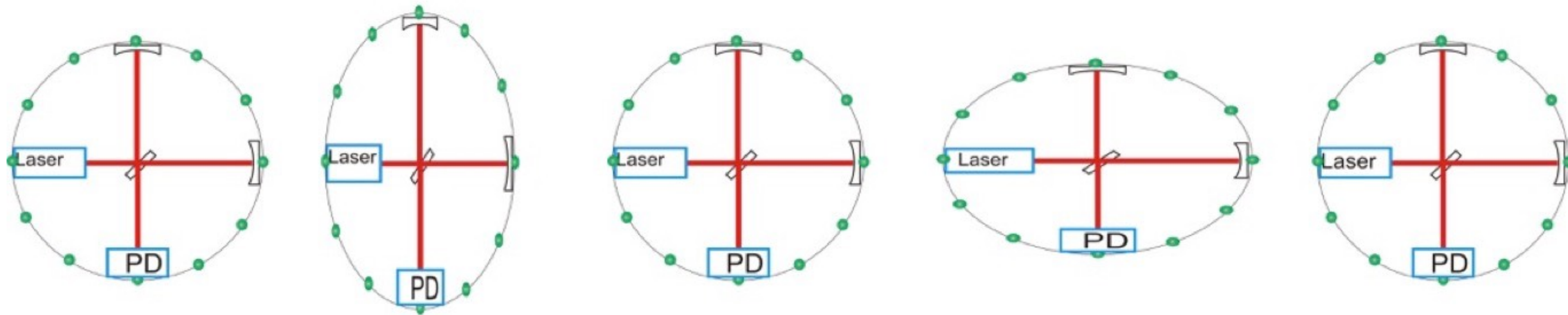
Data sets span months or years

A few TB per year

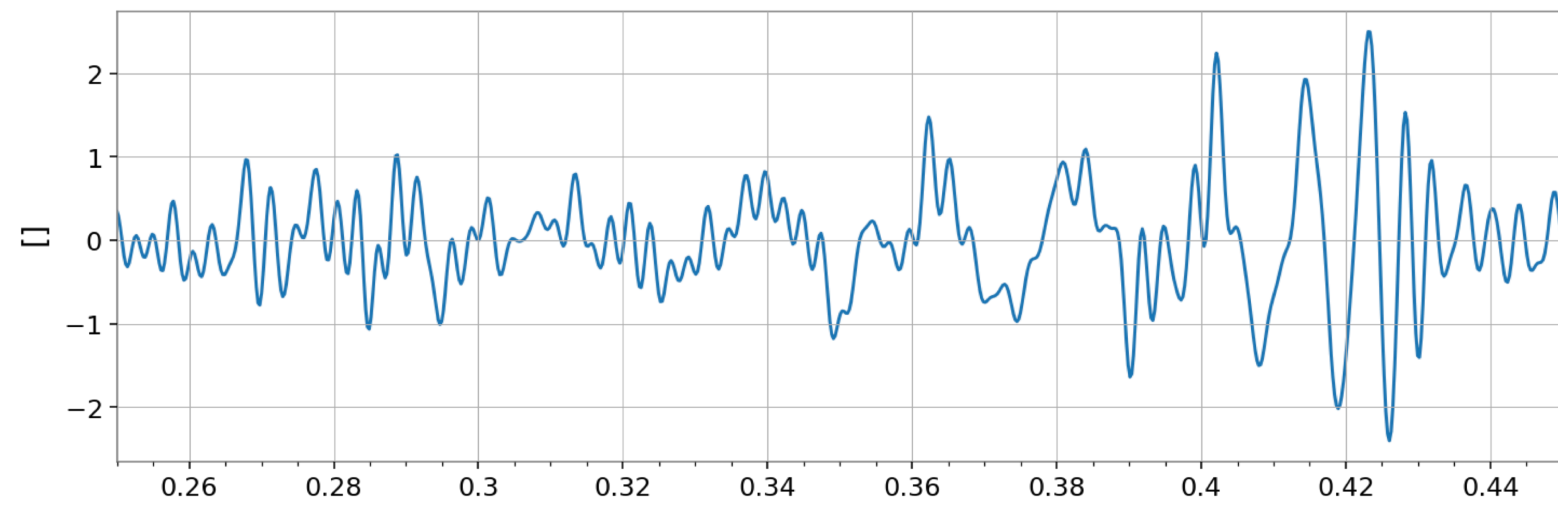
Detections last for seconds or less

Detections are hidden in noise

$$\frac{\Delta L}{L}$$







# Time Domain Strain Data



SoftwareX

Volume 13, January 2021, 100658



Original software publication

## Open data from the first and second observing runs of Advanced LIGO and Advanced Virgo

[Rich Abbott](#)<sup>1</sup> [✉](#), [Thomas D. Abbott](#)<sup>2</sup>, [Sheelu Abraham](#)<sup>3</sup>, [Fausto Acernese](#)<sup>4,5</sup>, [Kendall Ackley](#)<sup>6</sup>, [Carl Adams](#)<sup>7</sup>, [Rana X. Adhikari](#)<sup>1</sup>, [Vaishali B. Adya](#)<sup>8</sup>, [Christoph Affeldt](#)<sup>9,10</sup>, [Michalis Agathos](#)<sup>11,12</sup>, [Kazuhiro Agatsuma](#)<sup>13</sup>, [Nancy Aggarwal](#)<sup>14</sup>, [Odylio D. Aguiar](#)<sup>15</sup>, [Amit Aich](#)<sup>16</sup>, [Lorenzo Aiello](#)<sup>17,18</sup>, [Anirban Ain](#)<sup>3</sup>, [Ajith Parameswaran](#)<sup>19</sup>, [Gabrielle Allen](#)<sup>20</sup>, [Annalisa Allocca](#)<sup>21</sup>, [Paul A. Altin](#)<sup>8</sup>... [John Zweizig](#)<sup>1</sup>

[Show more](#) [v](#)

## THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES

OPEN ACCESS

### Open Data from the Third Observing Run of LIGO, Virgo, KAGRA, and GEO

R. Abbott<sup>1</sup>, H. Abe<sup>2</sup>, F. Acernese<sup>3,4</sup>, K. Ackley<sup>5</sup> [ID](#), S. Adhicary<sup>6</sup>, N. Adhikari<sup>7</sup> [ID](#), R. X. Adhikari<sup>1</sup> [ID](#), V. K. Adkins<sup>8</sup>, V. B. Adya<sup>9</sup>, C. Affeldt<sup>10,11</sup> [+ Show full author list](#)

Published 2023 July 28 • © 2023. The Author(s). Published by the American Astronomical Society.

[The Astrophysical Journal Supplement Series](#), [Volume 267](#), [Number 2](#)

Citation R. Abbott *et al* 2023 *ApJS* 267 29

DOI 10.3847/1538-4365/acdc9f

Published papers describe  
each data set



# Strain data file

```
H-H1_GWOSC_4KHZ_R1-1268903496-32.txt
# Gravitational wave strain for GW200322_091133-v1 for H1
# This file has 4096 samples per second
# starting GPS 1268903496 duration 32
-7.1980900594956013e-21
-6.8433397262034073e-21
-1.7612990400426759e-20
-9.4267311704874265e-21
-6.1983141016039667e-21
-1.3240125547300500e-20
-1.2532010942962005e-20
-1.6986963728113432e-20
-1.4093840416373476e-20
-9.5227443608221438e-21
-1.9064670104960347e-20
1.6122006160160277e-20
```

Formats:

GWTF  
or  
HDF5



# Strain data file

```
H-H1_GWOSC_4KHZ_R1-1268903496-32.txt
# Gravitational wave strain for GW200322_091133-v1 for H1
# This file has 4096 samples per second
# starting GPS 1268903496 duration 32
-7.1980900594956013e-21
-6.8433397262034073e-21
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-9.4267311704874265e-21
-6.1983141016039667e-21
-1.3240125547300500e-20
-1.2532010942962005e-20
-1.6986963728113432e-20
-1.4093840416373476e-20
-9.5227443608221438e-21
-1.9064670104960347e-20
1.6122006160160277e-20
```

Sample Rate

16384 Hz

or

4096 Hz



# Strain data file

```
H-H1_GWOSC_4KHZ_R1-1268903496-32.txt
# Gravitational wave strain for GW200322_091133-v1 for H1
# This file has 4096 samples per second
# starting GPS 1268903496 duration 32
-7.1980900594956013e-21
-6.8433397262034073e-21
-1.7612990400426759e-20
-9.4267311704874265e-21
-6.1983141016039667e-21
-1.3240125547300500e-20
-1.2532010942962005e-20
-1.6986963728113432e-20
-1.4093840416373476e-20
-9.5227443608221438e-21
-1.9064670104960347e-20
1.6122006160160277e-20
```

Start time

Time measured  
in GPS seconds



# Strain data file

```
H-H1_GWOSC_4KHZ_R1-1268903496-32.txt
# Gravitational wave strain for GW200322_091133-v1 for H1
# This file has 4096 samples per second
# starting GPS 1268903496 duration 32
-7.1980900594956013e-21
-6.8433397262034073e-21
-1.7612990400426759e-20
-9.4267311704874265e-21
-6.1983141016039667e-21
-1.3240125547300500e-20
-1.2532010942962005e-20
-1.6986963728113432e-20
-1.4093840416373476e-20
-9.5227443608221438e-21
-1.9064670104960347e-20
1.6122006160160277e-20
```

Strain values  
at each sample time

Time between samples

$$\Delta t = 1/f_s$$



# GPS

## Time

- Number of seconds from Jan 6, 1980 UTC
- Used by GPS satellites
- Convenient time convention for computers
- Conversion tool: [gwosc.org/gps](http://gwosc.org/gps)

# UTC/GPS Time Converter

---

Change either box and the other responds immediately.

UTC  
2024-04-05T22:17:24

Universal Time [ISO8601](https://www.iso.org/standard/52184.html)

GPS Time  
1396390662

OK

Current time



# Explore Strain: GW Quickview App

<https://gw-quickview.streamlit.app/>

**Select Data Time and Detector**

How do you want to find data?

By event name ▼

Select Event

GW150914 ▼

Detector

H1 ▼

Full sample rate data

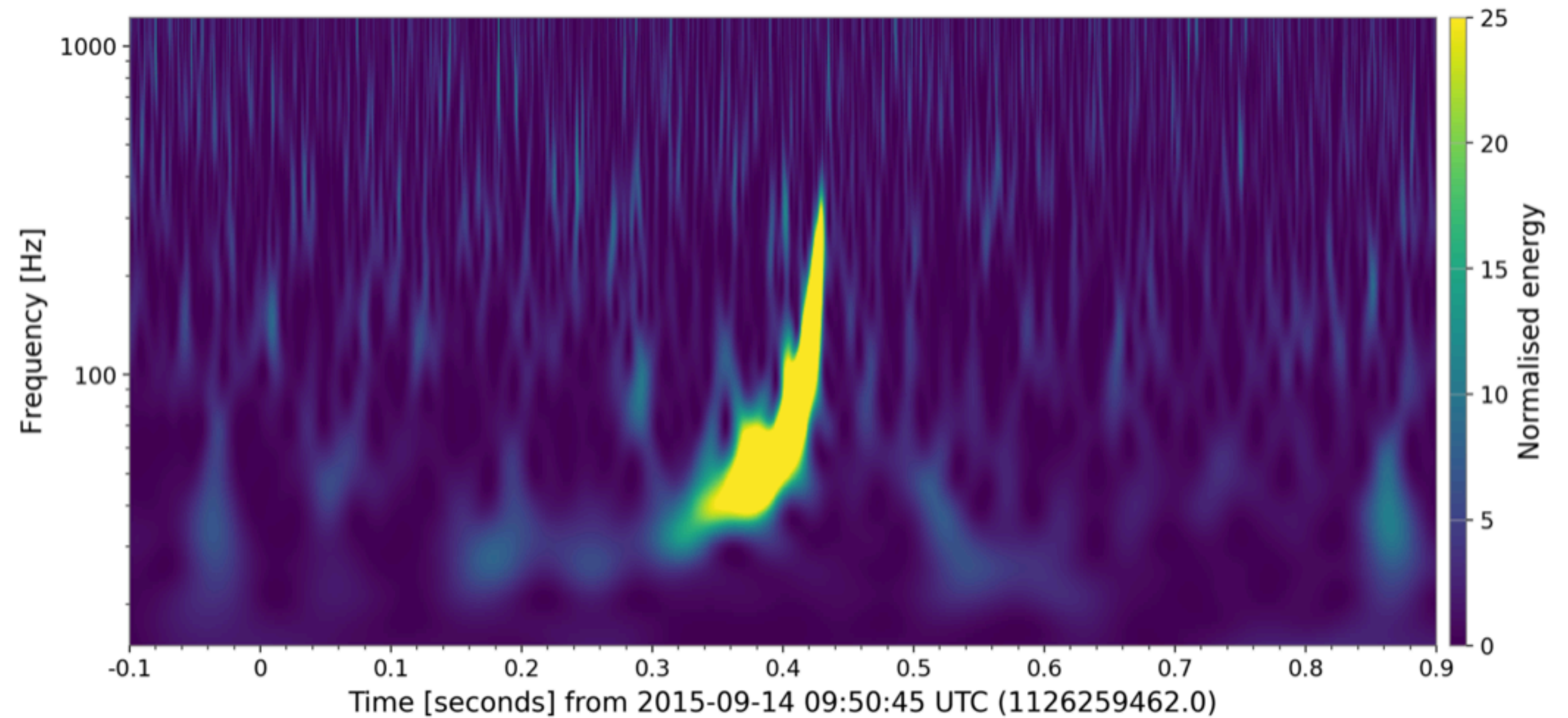
**Set Plot Parameters**

Time Range (seconds)

1.00

0.10 8.00

## Q-transform



See notes ▼

**About this app**



### Select Data Time and Detector

How do you want to find data?

By event name

Select Event

GW151012

Detector

H1

Full sample rate data

### Set Plot Parameters

Time Range (seconds)

0.44

# Gravitational Wave Quickview

- Use the menu at left to select data and set plot parameters
- Your plots will appear below

## GW151012

GPS: 1128678900.4

Mass 1: 23.2 M<sub>⊙</sub>

Mass 2: 13.6 M<sub>⊙</sub>

Network SNR: 10

Event page: <https://gw-osc.org/eventapi/html/event/GW151012>

Loading data...done!



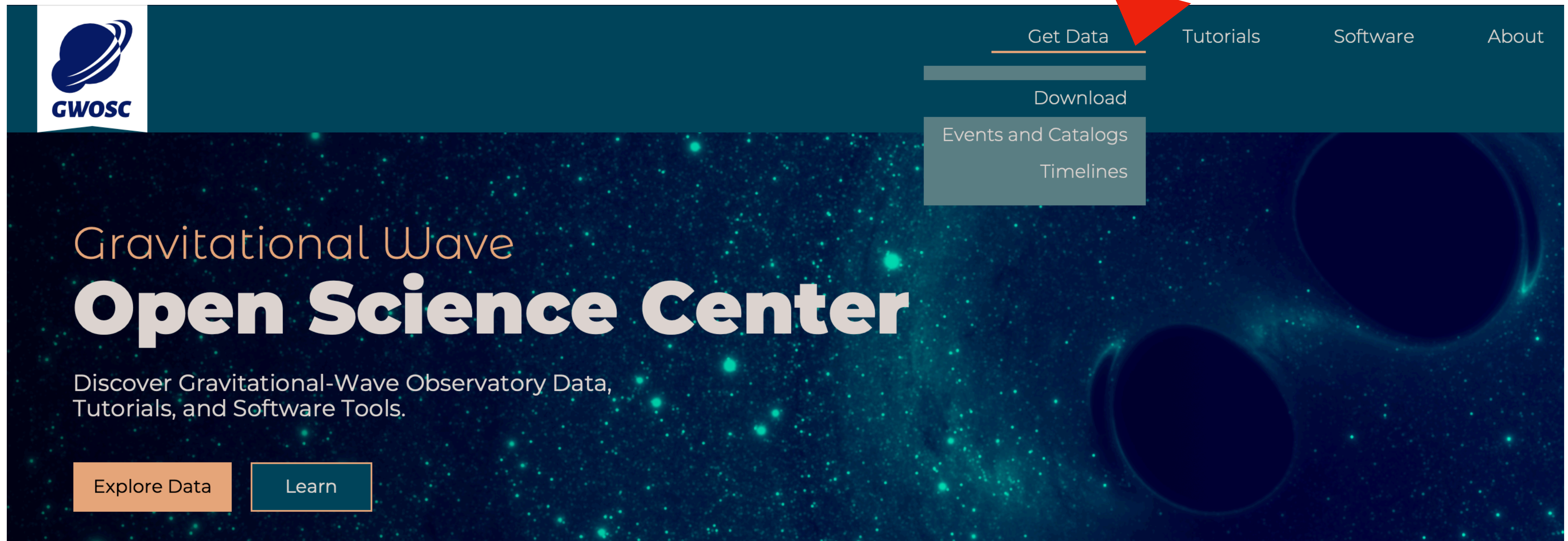
# Download Strain Data

## 1) Point & Click



# Download Strain Data

## 1) Point & Click

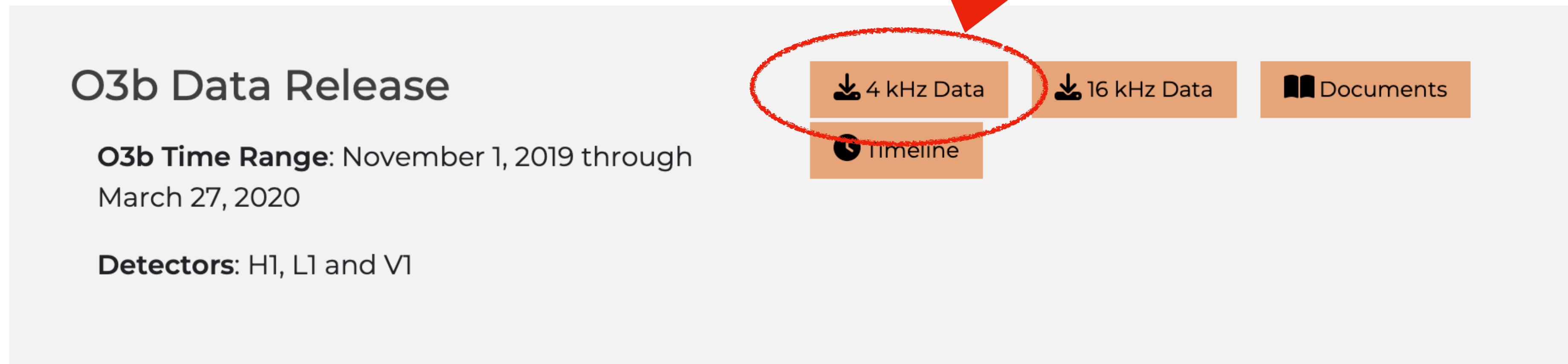


The image shows a screenshot of the Gravitational Wave Open Science Center (GWOSC) website. The top navigation bar is dark teal and contains the GWOSC logo on the left and the links 'Get Data', 'Tutorials', 'Software', and 'About' on the right. A red arrow points to the 'Get Data' link, which has a dropdown menu open. The dropdown menu contains three items: 'Download', 'Events and Catalogs', and 'Timelines'. Below the navigation bar, the main content area has a dark blue background with a starry pattern. The text 'Gravitational Wave Open Science Center' is displayed in large, bold, white letters. Below this, a smaller line of text reads 'Discover Gravitational-Wave Observatory Data, Tutorials, and Software Tools.' At the bottom left, there are two buttons: 'Explore Data' (orange) and 'Learn' (teal).



# Download Strain Data


## 1) Point & Click





**O3b Data Release**


**O3b Time Range:** November 1, 2019 through March 27, 2020

**Detectors:** H1, L1 and V1

 4 kHz Data

 16 kHz Data

 Documents

 Timeline

A red arrow points from the top right towards the '4 kHz Data' button, which is also circled in red. The interface is a light gray panel with text and buttons.

# Download Strain Data

## 1) Point & Click

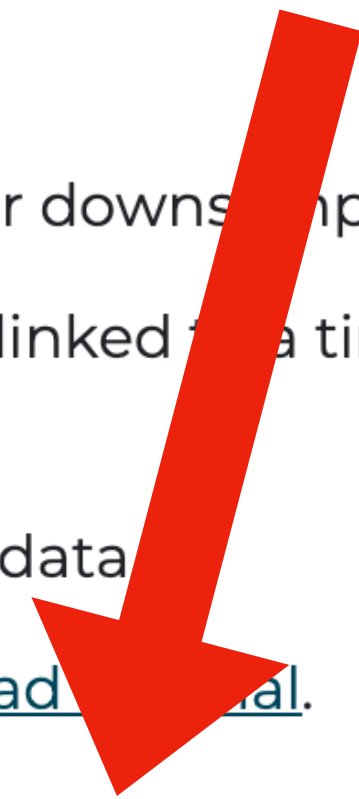
**Dataset:** O3b\_4KHZ\_R1

**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 file 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
<a href="#">1256660992</a>	2019-11-01T16:29:34	50.4 MB	<a href="#">HDF5</a>	<a href="#">Frame</a>	40.2
<a href="#">1256665088</a>	2019-11-01T17:37:50	124.3 MB	<a href="#">HDF5</a>	<a href="#">Frame</a>	100.0
<a href="#">1256669184</a>	2019-11-01T18:46:06	124.3 MB	<a href="#">HDF5</a>	<a href="#">Frame</a>	100.0



# Download Strain Data

**1) Point & Click**

**2) Python Client**

# Download Strain Data

## 1) Point & Click

## 2) Python Client

```
>>> from gwosc.locate import get_urls
>>> get_urls('L1', 968650000, 968660000)
['https://gwosc.org/archive/data/S6/967835648/L-L1_L0SC_4_V1-968646656-4096.hdf5',
 'https://gwosc.org/archive/data/S6/967835648/L-L1_L0SC_4_V1-968650752-4096.hdf5',
 'https://gwosc.org/archive/data/S6/967835648/L-L1_L0SC_4_V1-968654848-4096.hdf5',
 'https://gwosc.org/archive/data/S6/967835648/L-L1_L0SC_4_V1-968658944-4096.hdf5']
```



# Download Strain Data

**1) Point & Click**

**2) Python Client**

**3) Direct load w/ gwpy**

# Download Strain Data

1) Point & Click

2) Python Client

3) Direct load w/ gwpy

```
>>> from gwpy.timeseries import TimeSeries  
>>> data = TimeSeries.fetch_open_data('L1', start, end)
```



# Download Strain Data

**1) Point & Click**

**2) Python Client**

**3) Direct load w/ gwpy**

**4) Extended release: NDS2 & CVMFS**

# Download Strain Data

```
from gwpy.timeseries import TimeSeries
data = TimeSeries.fetch('L1:ISI-GND_STS_ITMY_Z_BLRMS_30M_100M',
start=1266624018, end=1266624618, host='nds.gwosc.org')
```

4) Extended release: **NDS2** & **CVMFS**

CVMFS available on Open Science Grid  
& other computer clusters



# Download Strain Data

**1) Point & Click**

**2) Python Client**

**3) Direct load w/ gwpy**

**4) Extended release: NDS2 & CVMFS**

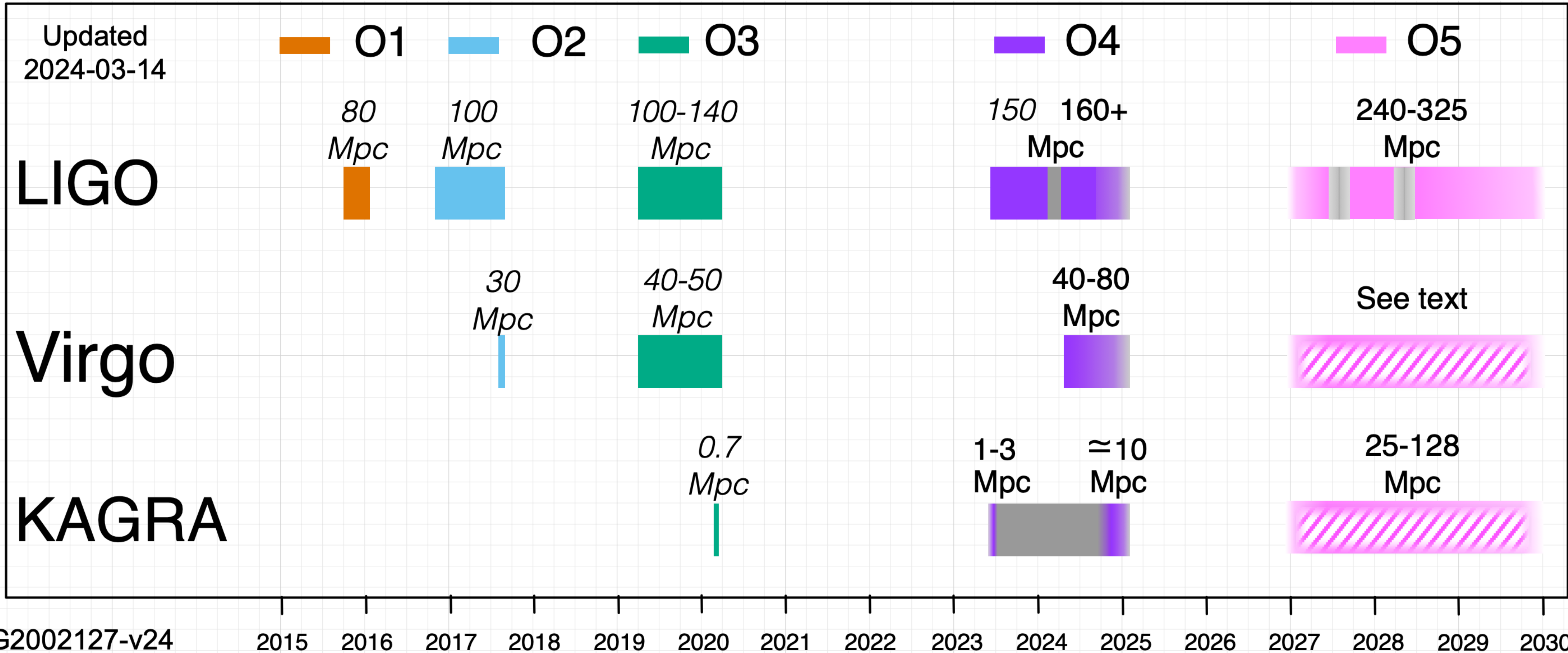
# Timeline App & Segments

**When are data available?**



# Timeline App & Segments

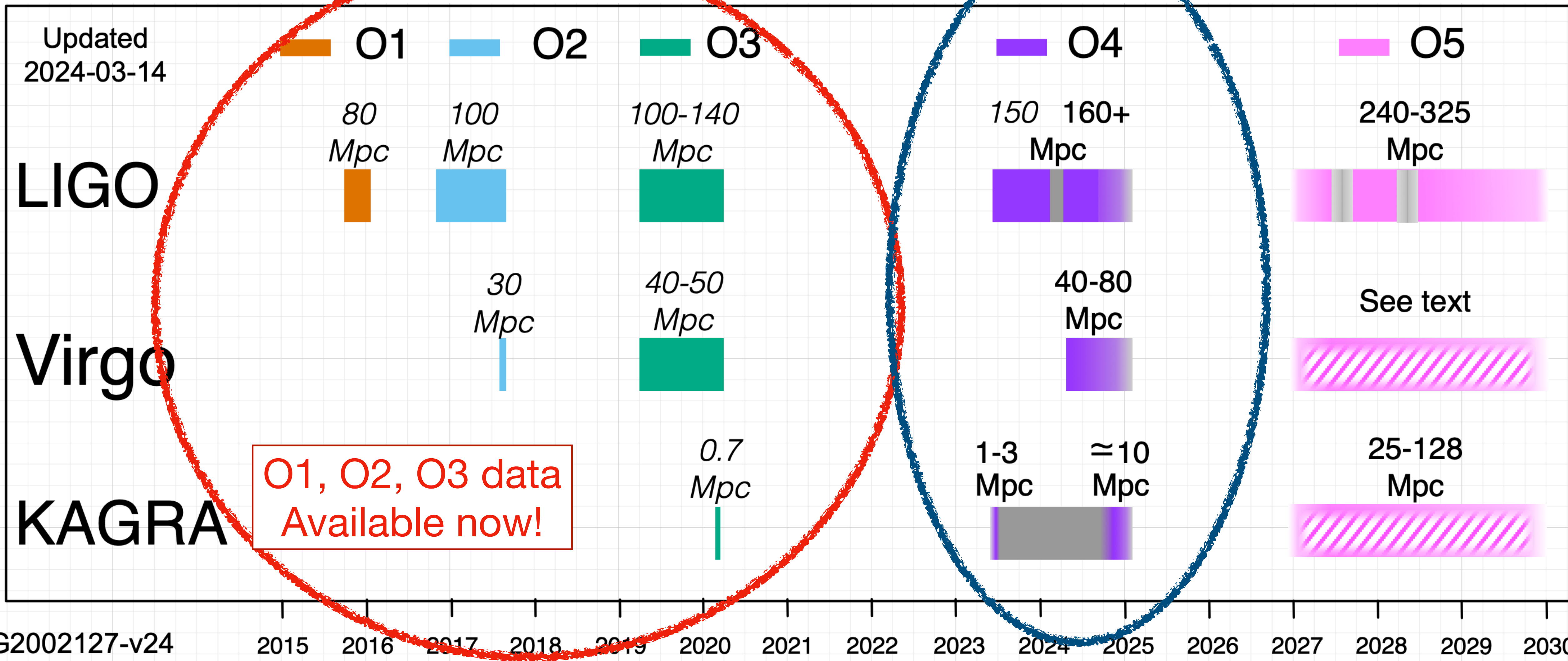
When are data available?



# Timeline App & Segments

## When are data available?

O4 run  
in progress



O1, O2, O3 data  
Available now!

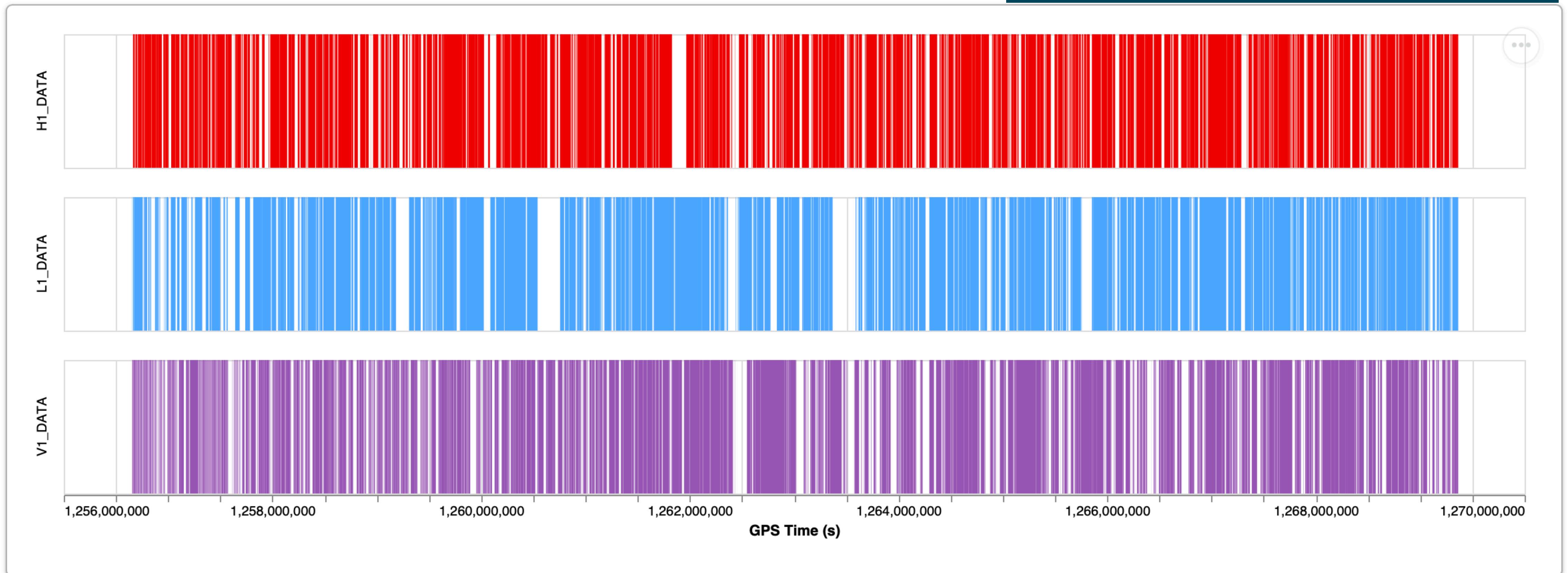


# Timeline App & Segments

When are data available?

[gwosc.org/timeline](http://gwosc.org/timeline)

Timeline O3b



# Event Catalogs

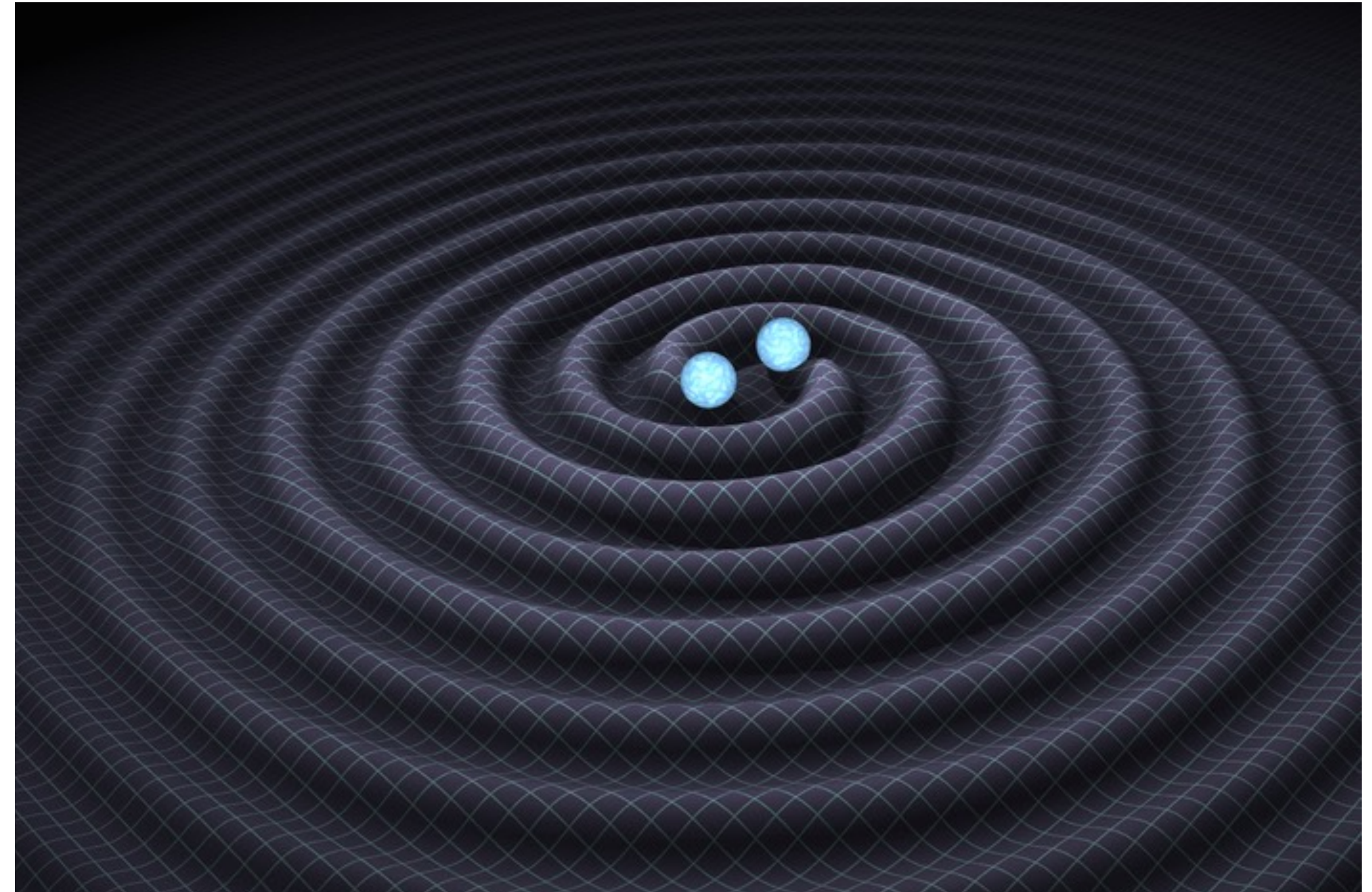
**What events has LIGO/Virgo/KAGRA seen?**



# Event Catalogs

## What events has LIGO/Virgo/KAGRA seen?

- Each “event” is a compact object merger
  - Mergers of black holes or neutron stars
- Observed for seconds or less
- Around 90 detections so far







# Gravitational Wave Open Science Center



Data ▾

Software ▾

Online Tools ▾

Learning Resources ▾

About GWOSC ▾

 Help

## Event Portal

GWTC Transient Catalog

Releases

Events

Query



# Event Query

Event Name:

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

Release:

GWTC-1-marginal  
GWTC-1-confident  
O1\_O2-Preliminary  
O3\_Discovery\_Papers

Restrict search to a Catalog Release

**i** Mass 1  
Range:

**i** Mass 2  
Range:

**i** Total Mass  
Range:

**i** Final Mass  
Range:

**i** Chirp Mass  
Range:

**i** Detector  
Frame Chirp  
Mass Range:

**i** Distance  
(Mpc) Range:

**i** Redshift  
Range:

**i** Network  
SNR Range:

**i**  $\chi_{\text{eff}}$  Range:

**i** False Alarm  
Rate Range:

**i**  $P_{\text{astro}}$  Range:

# IGWN Catalogs

## Event Portal

# List of Events

## Data Product

Name	Version	Release	GPS	Mass 1 ( $M_{\odot}$ )	Mass 2 ( $M_{\odot}$ )	Network SNR	Distance (Mpc)	$\chi_{\text{eff}}$	Total Mass ( $M_{\odot}$ )	Chirp M
<a href="#">GW200322_091133</a>	v1	<a href="#">GWTC-3-confident</a>	1268903511.3	$34^{+48}_{-18}$	$14.0^{+16.8}_{-8.7}$	$6.0^{+1.7}_{-1.2}$	$3600^{+7000}_{-2000}$	$0.24^{+0.45}_{-0.51}$	$55^{+37}_{-27}$	$15.5^{+15.7}_{-3.7}$
<a href="#">GW200316_215756</a>	v1	<a href="#">GWTC-3-confident</a>	1268431094.1	$13.1^{+10.2}_{-2.9}$	$7.8^{+1.9}_{-2.9}$	$10.3^{+0.4}_{-0.7}$	$1120^{+470}_{-440}$	$0.13^{+0.27}_{-0.10}$	$21.2^{+7.2}_{-2.0}$	$8.75^{+0.6}_{-0.5}$
<a href="#">GW200311_115853</a>	v1	<a href="#">GWTC-3-confident</a>	1267963151.3	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$17.8^{+0.2}_{-0.2}$	$1170^{+280}_{-400}$	$-0.02^{+0.16}_{-0.20}$	$61.9^{+5.3}_{-4.2}$	$26.6^{+2.4}_{-2.0}$
<a href="#">GW200308_173609</a>	v1	<a href="#">GWTC-3-confident</a>	1267724187.7	$36.4^{+11.2}_{-9.6}$	$13.8^{+7.2}_{-3.3}$	$7.1^{+0.5}_{-0.5}$	$5400^{+2700}_{-2600}$	$0.65^{+0.17}_{-0.21}$	$50.6^{+10.9}_{-8.5}$	$19.0^{+4.8}_{-2.8}$
<a href="#">GW200306_093714</a>	v1	<a href="#">GWTC-3-confident</a>	1267522652.1	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$7.8^{+0.4}_{-0.6}$	$2100^{+1700}_{-1100}$	$0.32^{+0.28}_{-0.46}$	$43.9^{+11.8}_{-7.5}$	$17.5^{+3.5}_{-3.0}$
<a href="#">GW200302_015811</a>	v1	<a href="#">GWTC-3-confident</a>	1267149509.5	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$10.8^{+0.3}_{-0.4}$	$1480^{+1020}_{-700}$	$0.01^{+0.25}_{-0.26}$	$57.8^{+9.6}_{-6.9}$	$23.4^{+4.7}_{-3.0}$
<a href="#">GW200225_060421</a>	v1	<a href="#">GWTC-3-confident</a>	1266645879.3	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$12.5^{+0.3}_{-0.4}$	$1150^{+510}_{-530}$	$-0.12^{+0.17}_{-0.28}$	$33.5^{+3.6}_{-3.0}$	$14.2^{+1.5}_{-1.4}$
<a href="#">GW200224_222234</a>	v1	<a href="#">GWTC-3-confident</a>	1266618172.4	$40.0^{+6.9}_{-4.5}$	$32.5^{+5.0}_{-7.2}$	$20.0^{+0.2}_{-0.2}$	$1710^{+490}_{-640}$	$0.10^{+0.15}_{-0.15}$	$72.2^{+7.2}_{-5.1}$	$31.1^{+3.2}_{-2.6}$
<a href="#">GW200220_124850</a>	v1	<a href="#">GWTC-3-confident</a>	1266238148.1	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$8.5^{+0.3}_{-0.5}$	$4000^{+2800}_{-2200}$	$-0.07^{+0.27}_{-0.33}$	$67^{+17}_{-12}$	$28.2^{+7.3}_{-5.1}$
<a href="#">GW200220_061928</a>	v1	<a href="#">GWTC-3-confident</a>	1266214786.7	$87^{+40}_{-23}$	$61^{+26}_{-25}$	$7.2^{+0.4}_{-0.7}$	$6000^{+4800}_{-3100}$	$0.06^{+0.40}_{-0.38}$	$148^{+55}_{-33}$	$62^{+23}_{-15}$

# Event Catalogs

## Event Portal

### GW200129\_065458

# Single Event Data Product

#### Documentation

Release: GWTC-3-confident

Event UID: GW200129\_065458-v1

Names: GW200129\_065458

GPS: 1264316116.4

UTC Time: 2020-01-29 06:54

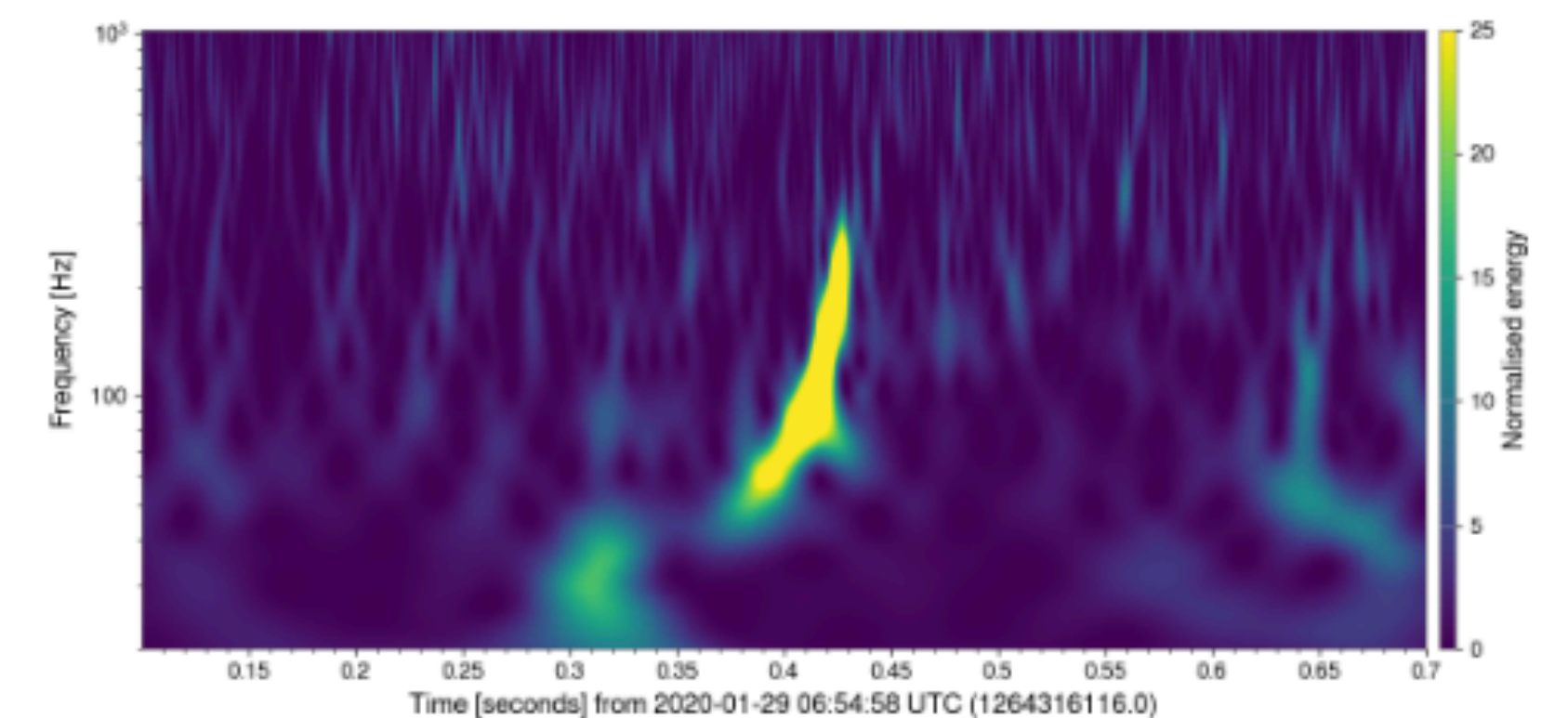
GraceDB: S200129m

GCN: Notices · Circulars

Timeline: [Query for segments](#)

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

#### H1 strain



32sec · 16KHz: [GWF](#) [HDF](#) [TXT](#)

32sec · 4KHz: [GWF](#) [HDF](#) [TXT](#)

4096sec · 16KHz: [GWF](#) [HDF](#) [TXT](#)

4096sec · 4KHz: [GWF](#) [HDF](#) [TXT](#)

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 ]



# Software and Tools

## Select Data Time and Detector

How do you want to find data?

By event name



Select Event

GW170608



Detector

H1

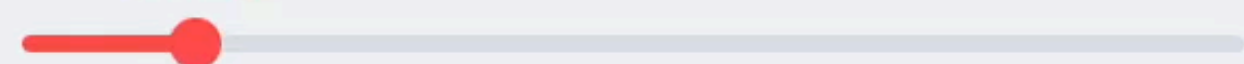


Full sample rate data

## Set Plot Parameters

Time Range (seconds)

1.22



0.10

8.00

Whitened and band-passed data

Whiten?

# Gravitational Wave Quickview

- Use the menu at left to select data and set plot parameters
- Your plots will appear below

## GW170608

GPS: 1180922494.5

Mass 1: 11.0  $M_{\odot}$

Mass 2: 7.6  $M_{\odot}$

Network SNR: 15

Event page: <https://gwosc.org/eventapi/html/event/GW170608>

Loading data...done!

## Raw data

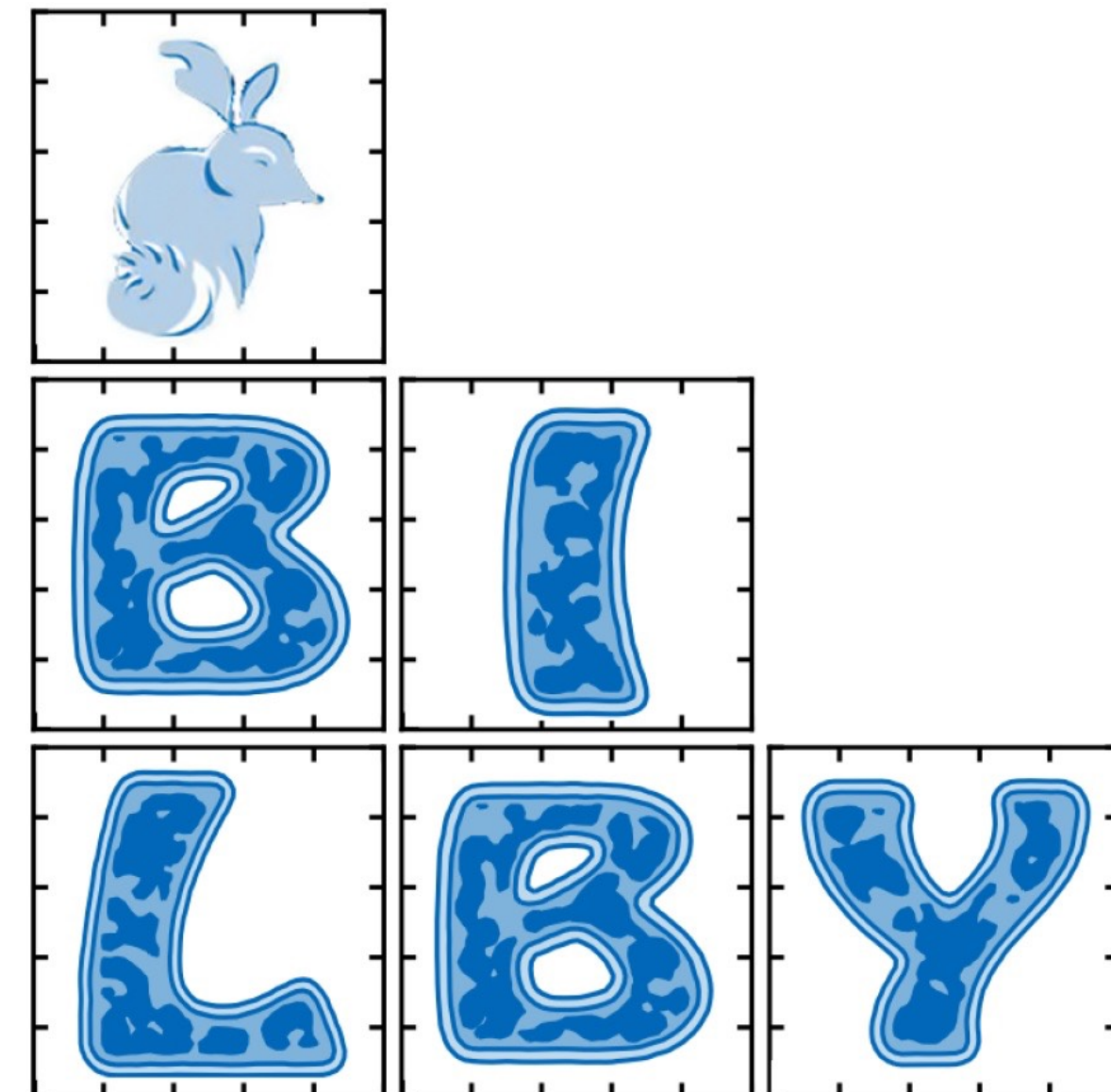
1.0  $\times 10^{-18}$



# Software

[gwosc.org/software](http://gwosc.org/software)

- IGWN Conda Software Distribution
  - —> install full LVK software stack
- PyPY (pip) also possible in many cases



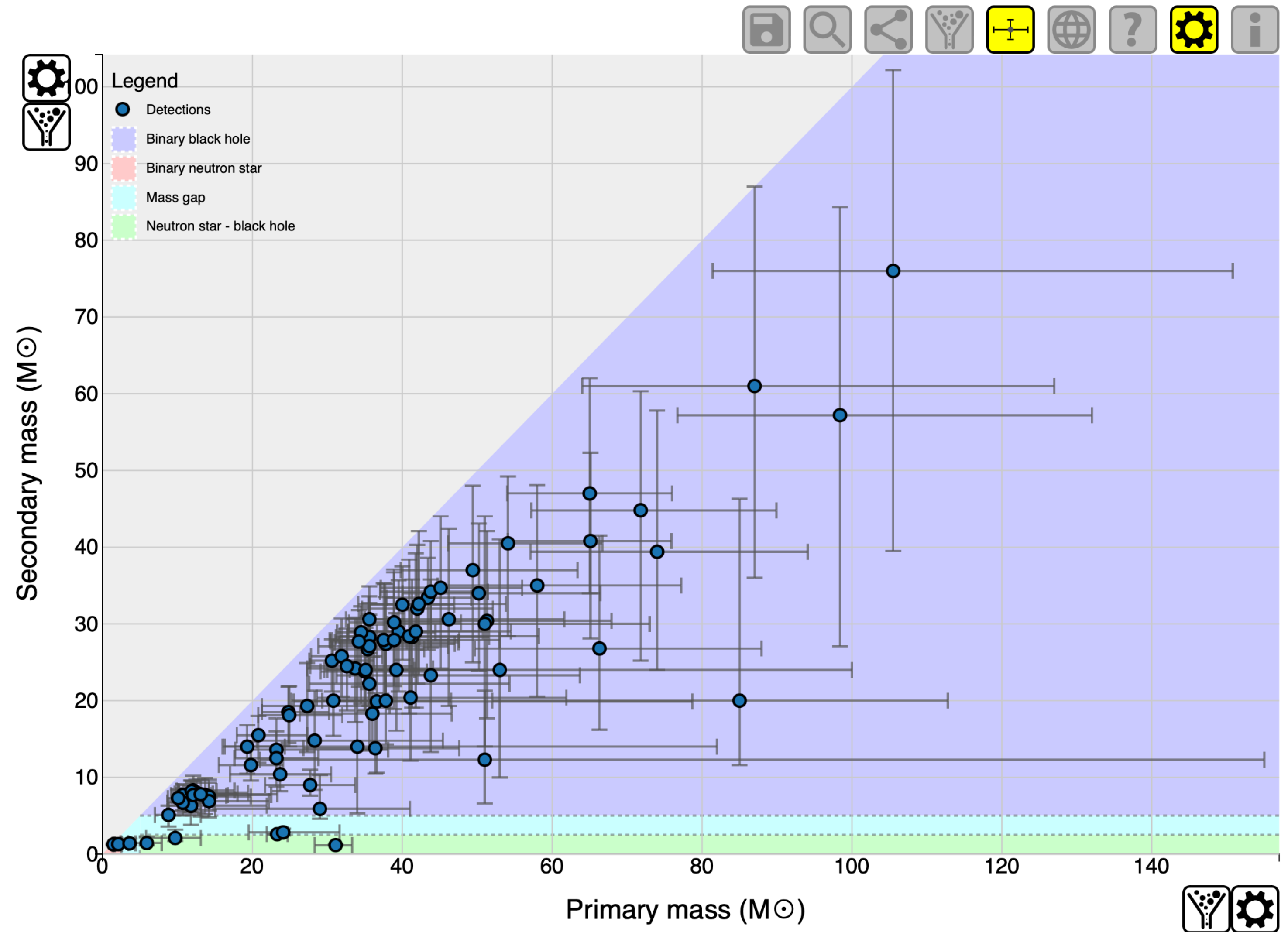


# Web Apps

[gwosc.org/interactive](http://gwosc.org/interactive)

- List of apps for GW data
- Plotting tools, games, phone apps

## Cardiff University GW Catalog Plotting App



# Get help!

[ask.igwn.org](https://ask.igwn.org)

- Discussion forum
- Post questions (and answers!)
- Use it for this workshop!

▼

## Welcome to the gravitational wave community forum

A community for discussion of gravitational wave science with LIGO, Virgo, and KAGRA.

categories ▾

tags ▾

Categories

Latest
Unread (3)
Top

+ New Category

+ New Topic

Category	Topics
<p><b>Open Data Workshop</b></p> <p>Discussion related to the Gravitational Wave Open Data Workshops.</p>	<p><b>39</b></p> <p>1 unread</p> <div style="background-color: #ccc; padding: 2px 5px; border-radius: 3px;">1 unread topic</div>
<p><b>Uncategorized</b></p> <p>Topics that don't need a category, or don't fit into any other existing category.</p>	<p><b>13</b></p>
<p><b>Data Analysis</b></p> <p>Post technical questions about working with gravitational wave data, debugging software, and signal processing.</p>	<p><b>61</b></p> <p>2 unread</p>





## Summary

# Gravitational Wave Open Science Center

Discover Gravitational-Wave Observatory Data,  
Tutorials, and Software Tools.

Explore Data

Learn

**Find times when data are available**  
**Download strain data**  
**Browse catalogs of events**  
**and more ....**

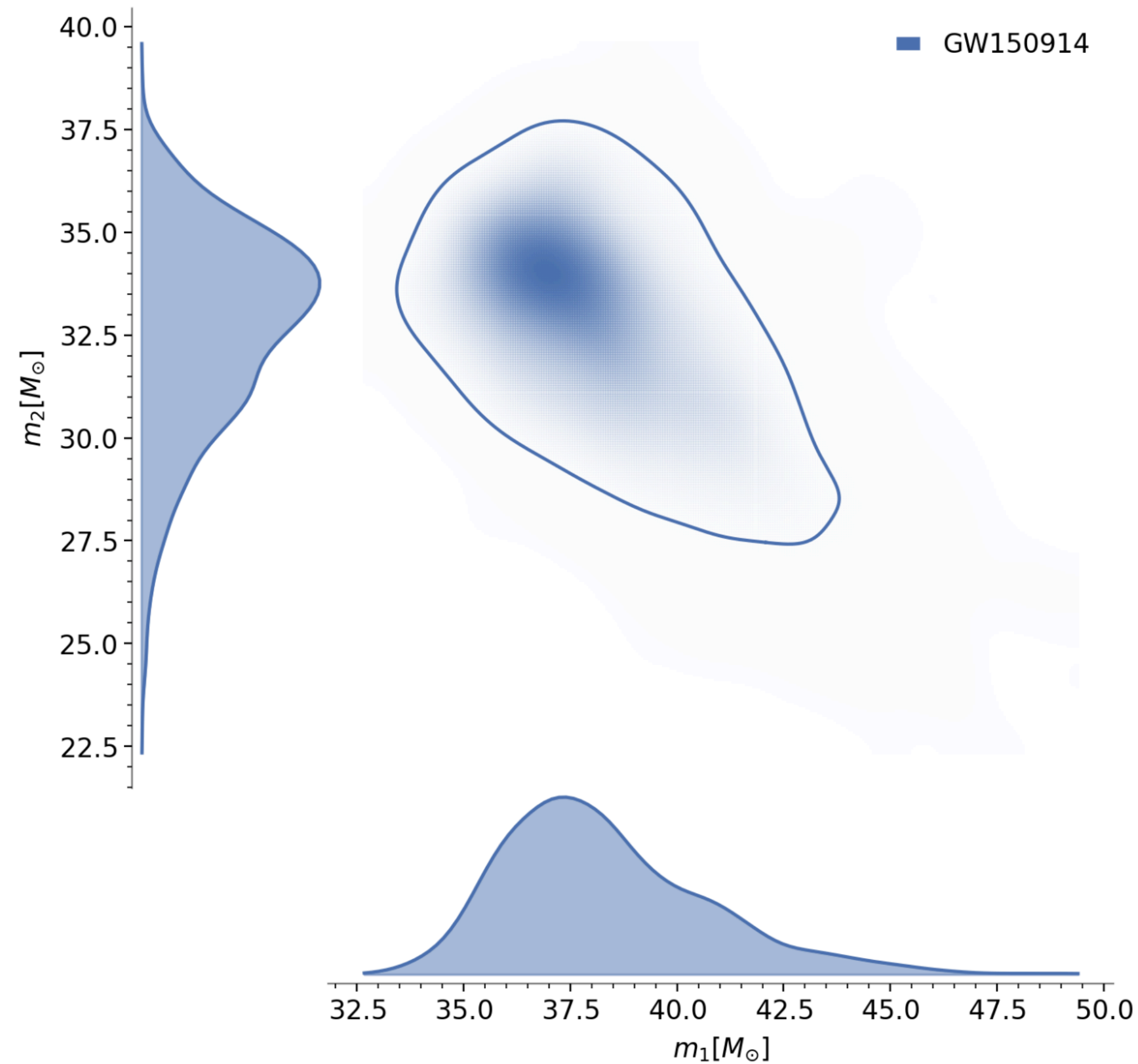
**[gwosc.org](http://gwosc.org)**



# Event Viewer App

## Visualize event parameters & waveforms

Triangle plot



H1

