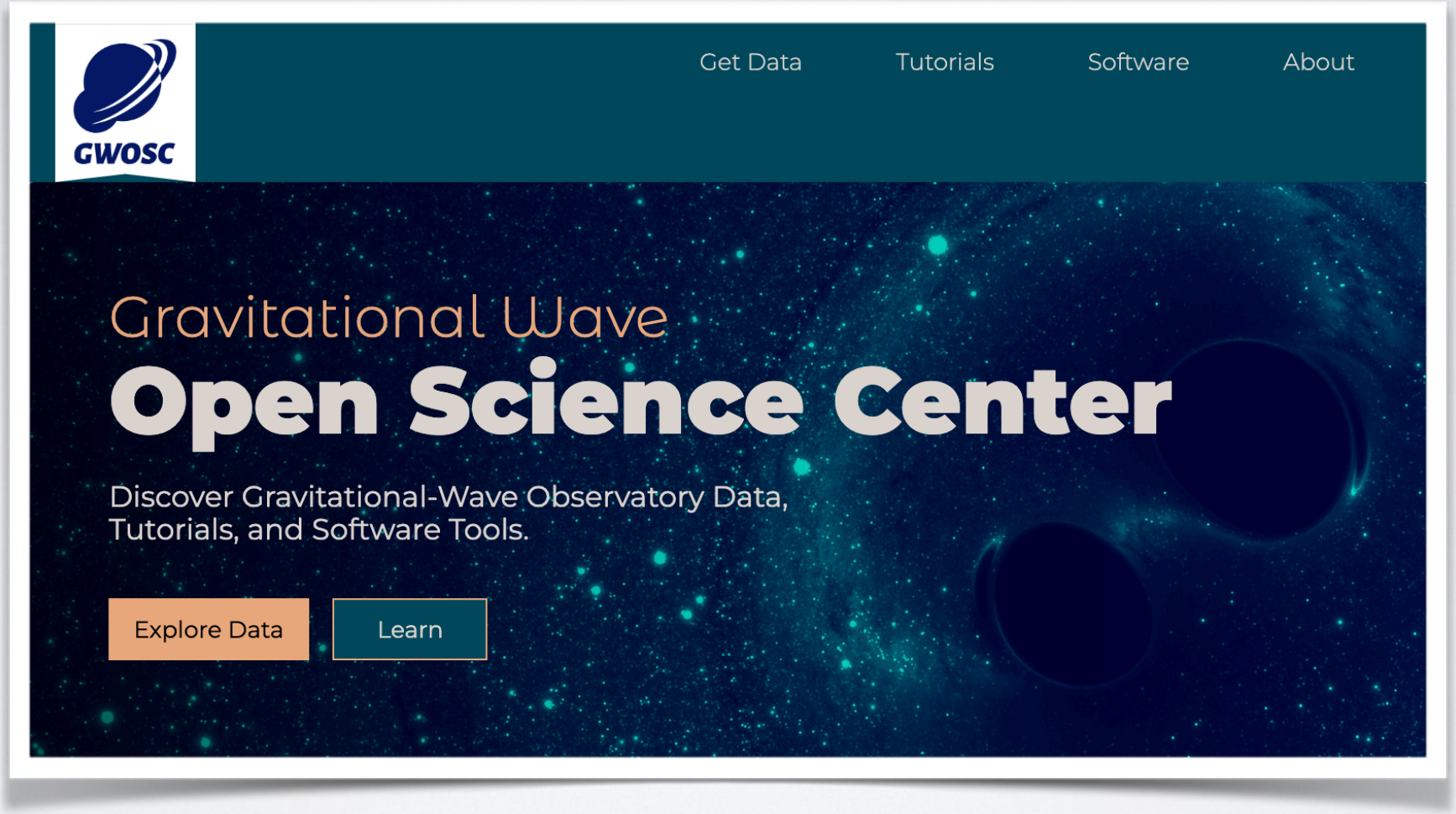
Public Portal for Gravitation Wave Data:

Introduction to the Gravitational Wave Open Science Center (GWOSC)



Kent Blackburn
LIGO Laboratory
California Institute Of Technology

WHY OPEN DATA?

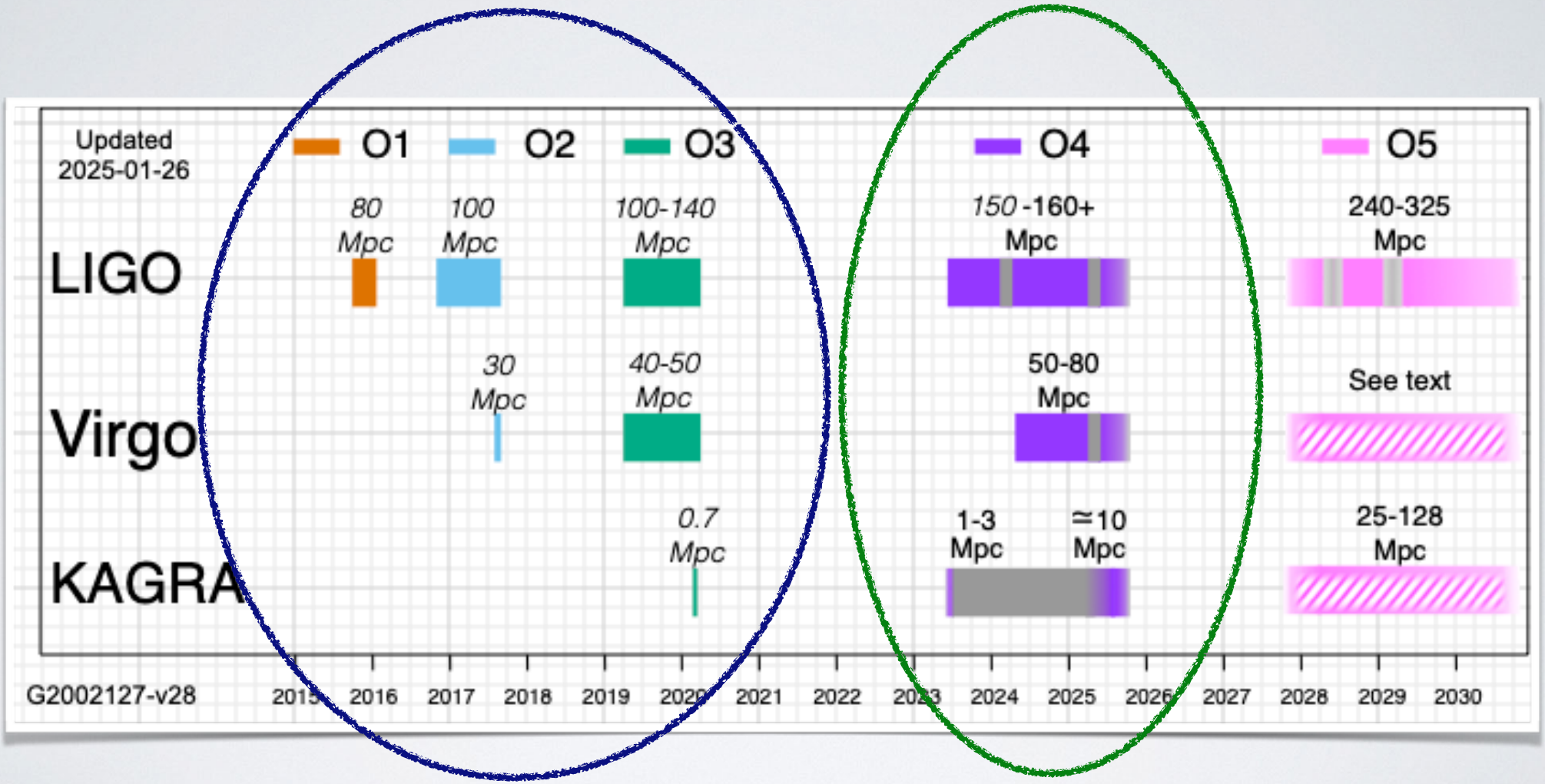
- **GWOSC** (*definition*)**:** The Gravitational Wave Open Science Center (GWOSC) is a public data repository that provides free access to gravitational wave data from LIGO, Virgo, and KAGRA. (**Data released under a CC BY 4.0 License**)
- **Goals:**
  - Promote accessibility, transparency (and reproducibility).
  - Foster collaboration and interdisciplinary programs crucial for solving complex problems in astrophysics.
  - Enable new discoveries from existing data.
- **Who Contributes:**
  - LIGO Scientific Collaboration (LSC), Virgo Collaboration, KAGRA Collaboration. (LVK).
  - Broader Community (Publications, Community Catalogs)

TYPES OF DATA++ ON GWOSC?

- Strain, Segment Lists (Timelines) / Data Quality
- Events and Catalogs:
  - Search & Parameter Estimation Results for Events
- Documentation
- References to Publications and Additional Data
- Tutorials / Workshops
- Software / Web Apps / GWOSC API / Libraries
- Data Formats:
  - GWF (frames) - custom data format developed by LIGO and Virgo to share data.
  - HDF5 - format developed by the HDF Group for storing and organizing large amounts of data, including metadata, efficiently.
  - An assortment of other formats for smaller files - JSON, CSV, ASCII

GETTING OBSERVATIONAL DATA

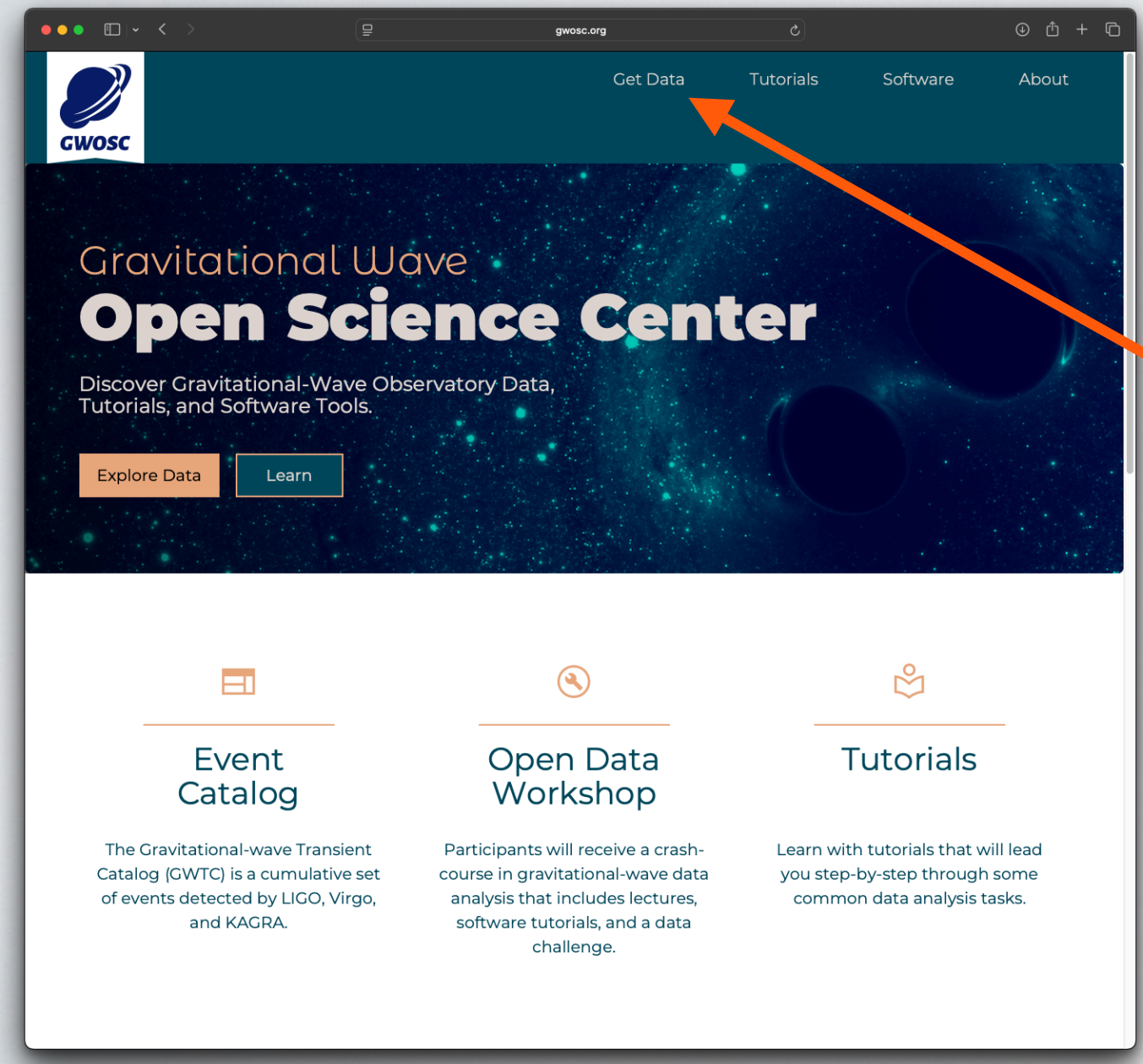
OBSERVATIONS



O1, O2, O3 Runs Available now!

O4 In Progress!

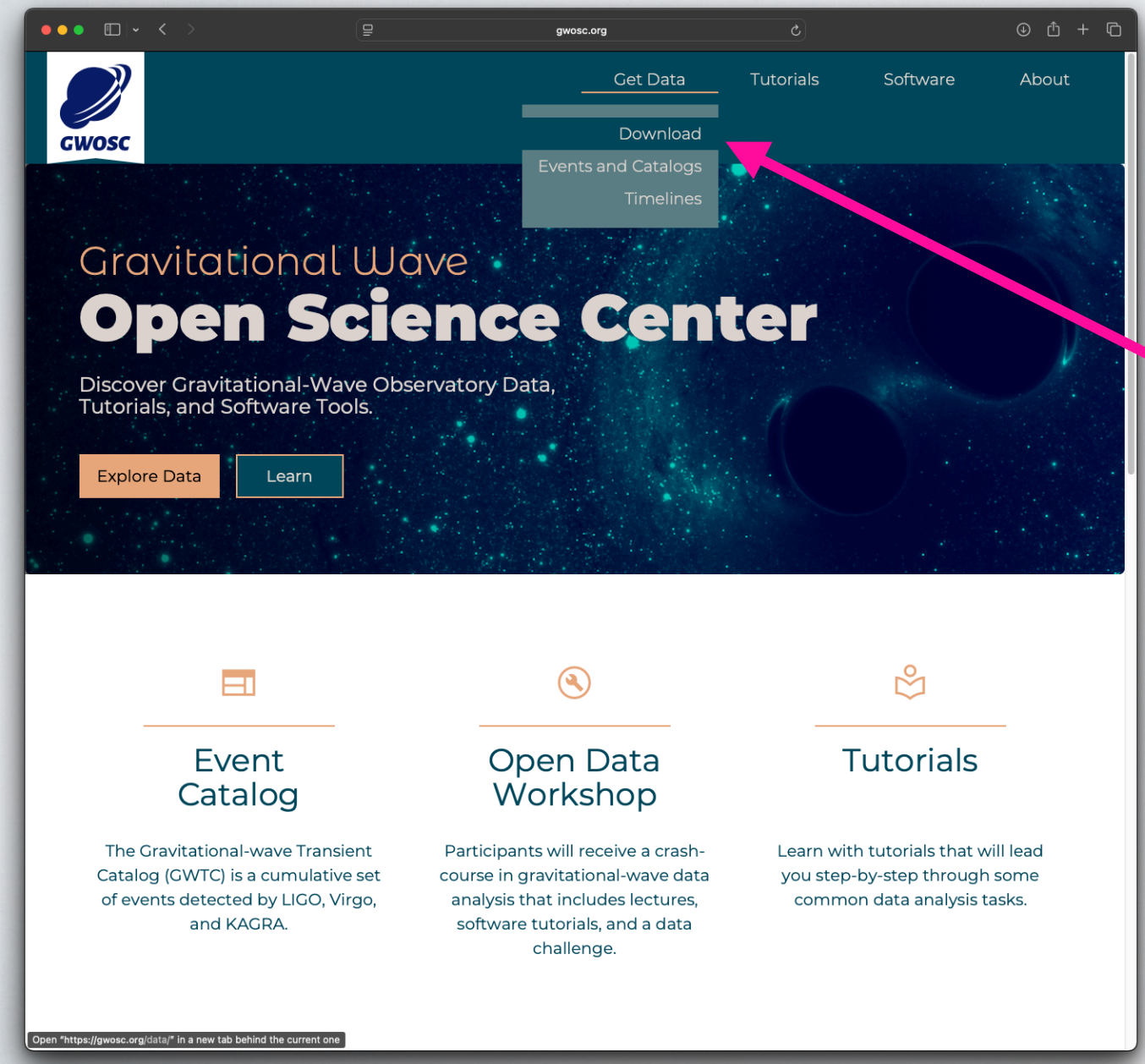
WEB BASED DATA DOWNLOAD



"Get Data" Pulldown Menu Gateway to getting all types of data products on GWOSC.

Click Here!

GETTING OBSERVING RUN DATA



Lets **download** an HDF5 file containing Hanford data from the O3b observing run.

Click Here!

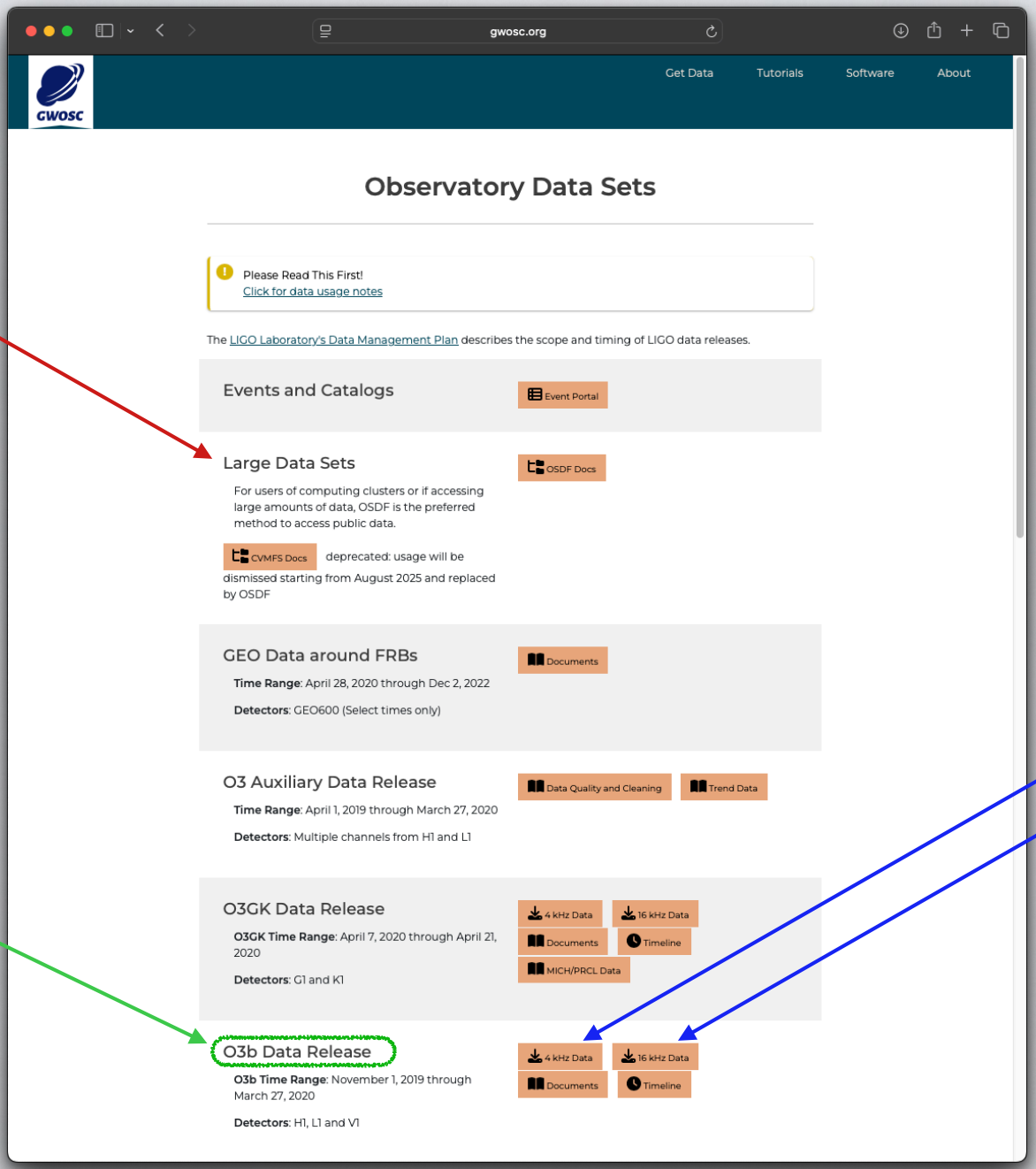
FIND THE "O3B DATA RELEASE"

Important!
If you need to use large amounts of data follow the set of instruction under the **OSDF Docs.**

1) Scroll down on the Observatory Data Sets page until you find the **O3b Data Release**.

2) Click on the sample rate you desire - 4kHz for a faster download, 16kHz if you want the most " samples per second.

We'll demonstrate with 4kHz Data!



SELECT DOWNLOAD DETAILS

We said we wanted the Hanford detector, so be sure H1 radio button is selected.

Select the output format for the presentation of the data to be downloaded.

I've selected the second radio button to allow me to visualize the quality of the data along side the download links.

When ready, select the **Continue** button to generate the download links to your data.

These are the start and end times for the O3b observing run, and the automatically selected as defaults in the user chosen start/end time section below.

Here is where the user is able to select a subset of start/end times to generate download links to choose from in the next step. I've down-selected to one day at the beginning of O3b.

RESULT: TABLE OF LINKS

Click on any of the **HDF5** or **Frame** links will download the strain data, with data quality as well, locally on your computer.

Timeline	UTC	Mbytes	HDF5	Frame	Seconds (of 4096) where flag is true											
					DATA	CBC_CAT1	CBC_CAT2	CBC_CAT3	BURST_CAT1	BURST_CAT2	BURST_CAT3	NO_CBC_HW_INJ	NO_BURST_HW_INJ	NO_DETCHAR_HW_INJ	NO_CW_HW_INJ	NO_STOCH_HW_INJ
1256660992	2019-11-01T16:29:34	50.4 MB	HDF5	Frame	40.2	40.2	40.2	40.2	40.2	39.6	39.6	100.0	100.0	100.0	0.0	100.0
1256665088	2019-11-01T17:37:50	124.3 MB	HDF5	Frame	100.0	100.0	100.0	100.0	100.0	99.3	99.3	100.0	100.0	100.0	0.0	100.0
1256669184	2019-11-01T18:46:06	124.3 MB	HDF5	Frame	100.0	100.0	100.0	100.0	100.0	99.7	99.7	100.0	100.0	100.0	0.0	100.0
1256673280	2019-11-01T19:54:22	124.3 MB	HDF5	Frame	100.0	100.0	100.0	100.0	100.0	99.7	99.7	100.0	100.0	100.0	0.0	100.0
1256677376	2019-11-01T21:02:38	62.4 MB	HDF5	Frame	49.9	49.9	49.9	49.9	49.9	49.7	49.7	100.0	100.0	100.0	0.0	100.0
1256681472	2019-11-01T22:10:54	84.4 MB	HDF5	Frame	67.7	67.7	67.7	67.7	67.7	67.5	67.5	100.0	100.0	100.0	0.0	100.0
1256685568	2019-11-01T23:19:10	65.0 MB	HDF5	Frame	52.0	52.0	52.0	52.0	52.0	52.0	52.0	100.0	100.0	100.0	0.0	100.0
1256689664	2019-11-	124.3 MB	HDF5	Frame	100.0	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.0	100.0	0.0	100.0

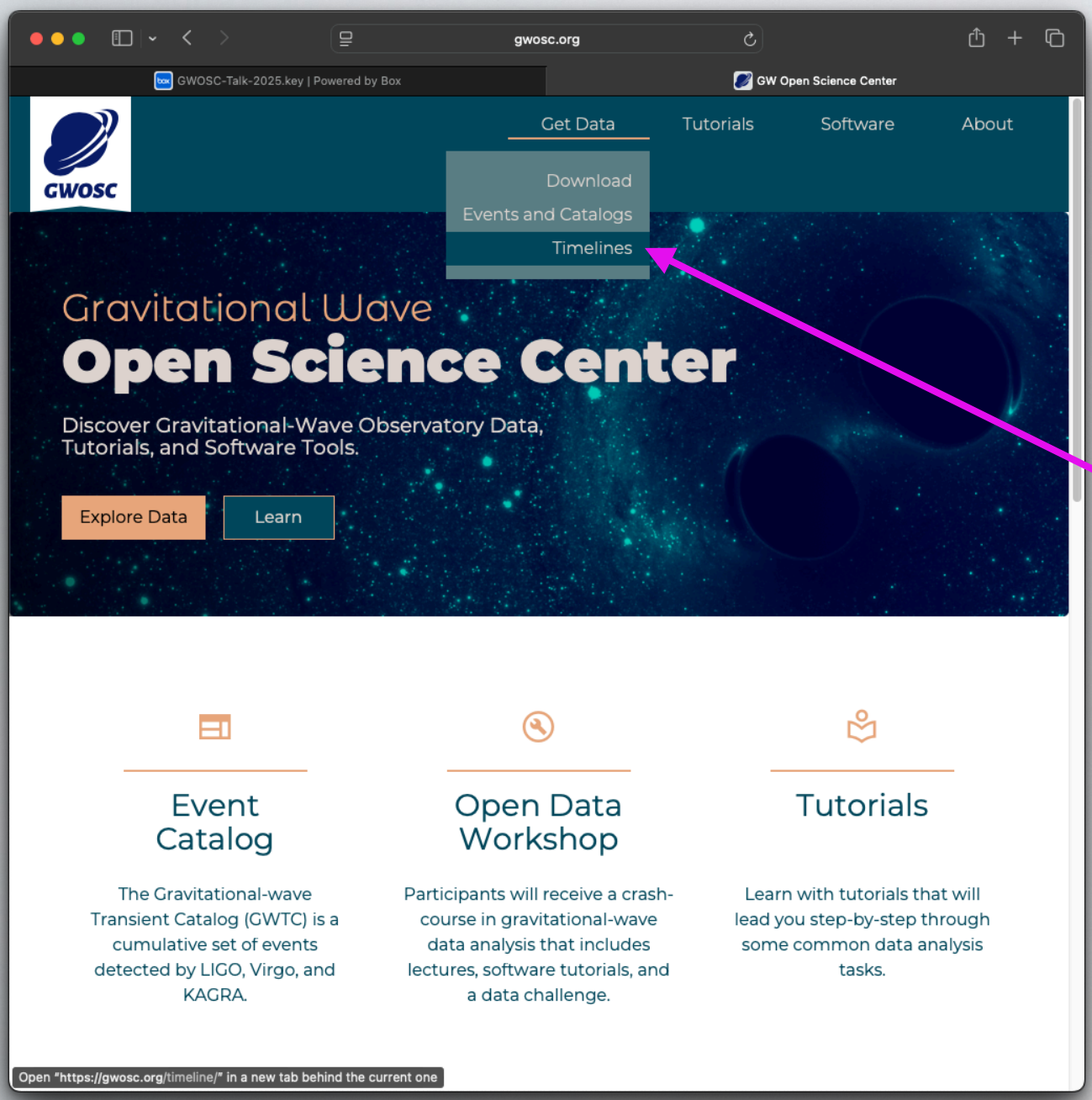
SEGMENTS, TIMELINES, AND DATA QUALITY

SEGMENT BASICS

Segments are simply lists of start and end time that characterize the state of the detectors and any irregularities that might have implications for astrophysical searches.

- During any time interval the detectors may be or may not be in observing "mode" (DATA flag).
- There may be irregularities in the detectors during observing mode that are detected using additional instrumentation on the environment and state (CAT1, CAT2 and CAT3 flags) that many interfere with searches for astrophysical searches (CBC & BURST) providing a measure of data quality.
- Man-made signals (**injections**) based on astrophysical models and detector noise signatures (sine-gaussians) may be added to the strain data for the purposes of calibration, search sensitivity, and in raw cases to challenge scientists. These are called injections and the times when these are added (or not added) are also available in the segments.
- Segment information (flags are also stored along side the strain data in GWF and HDF5 files.
- Segment lists can be visually displayed as timelines, or can be downloaded as JSON or ASCII.

GETTING SEGMENTS



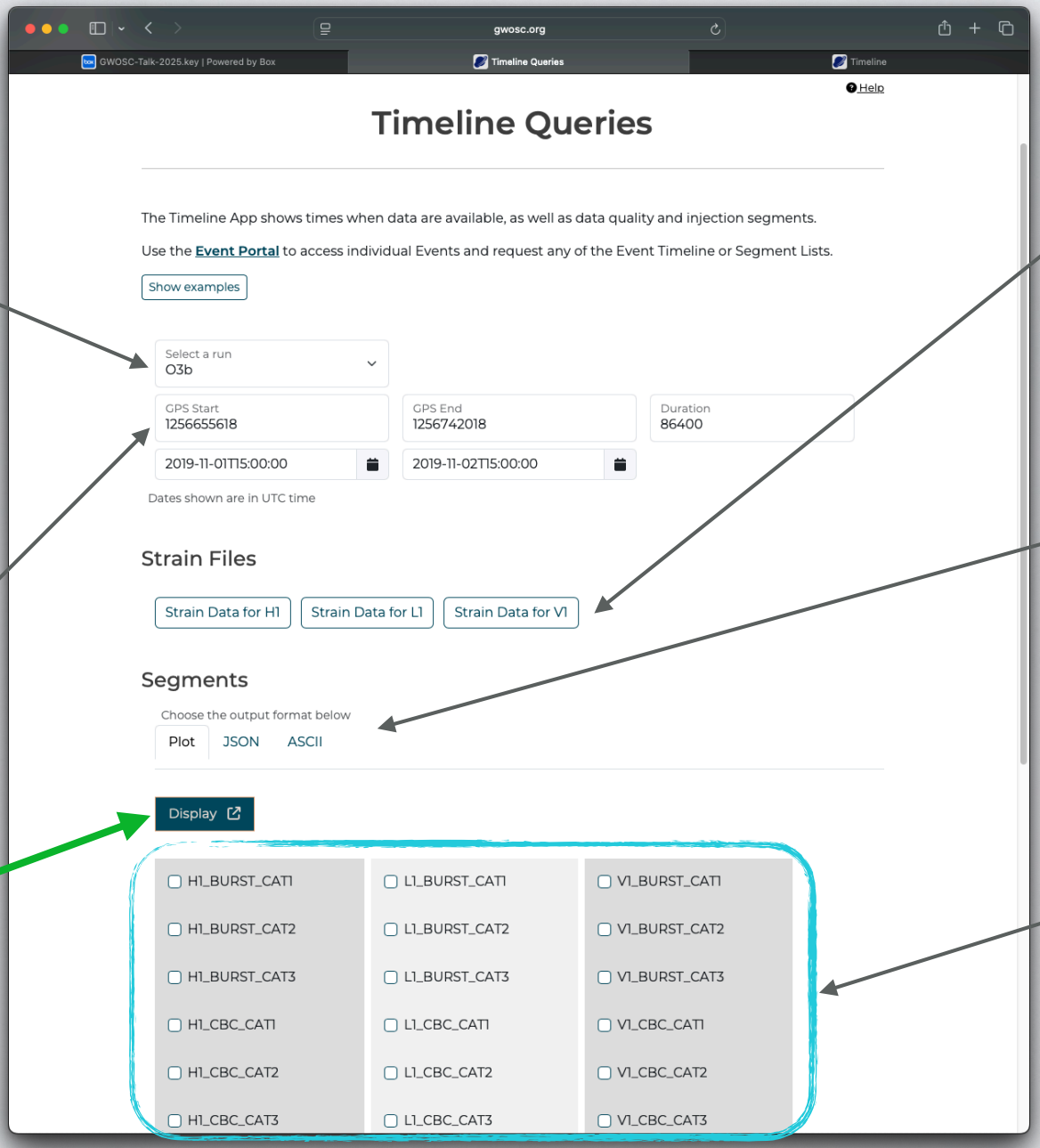
Select the **Timelines** to get segment info.

SELECTING SEGMENT DATA

Select desired Observing Run

Select Start and End times, UTC or GPS

When ready, click **Display**



Portals to Strain Data for each individual detector

Options for output format

Assortment of Data Quality Flags for each detector

DATA QUALITY OPTIONS

Select the **Display** button to visualize the selected data quality flags

Detector is in Observing Mode, select any detector you would like to plot

These are search sensitive data quality options that may have additional data cuts

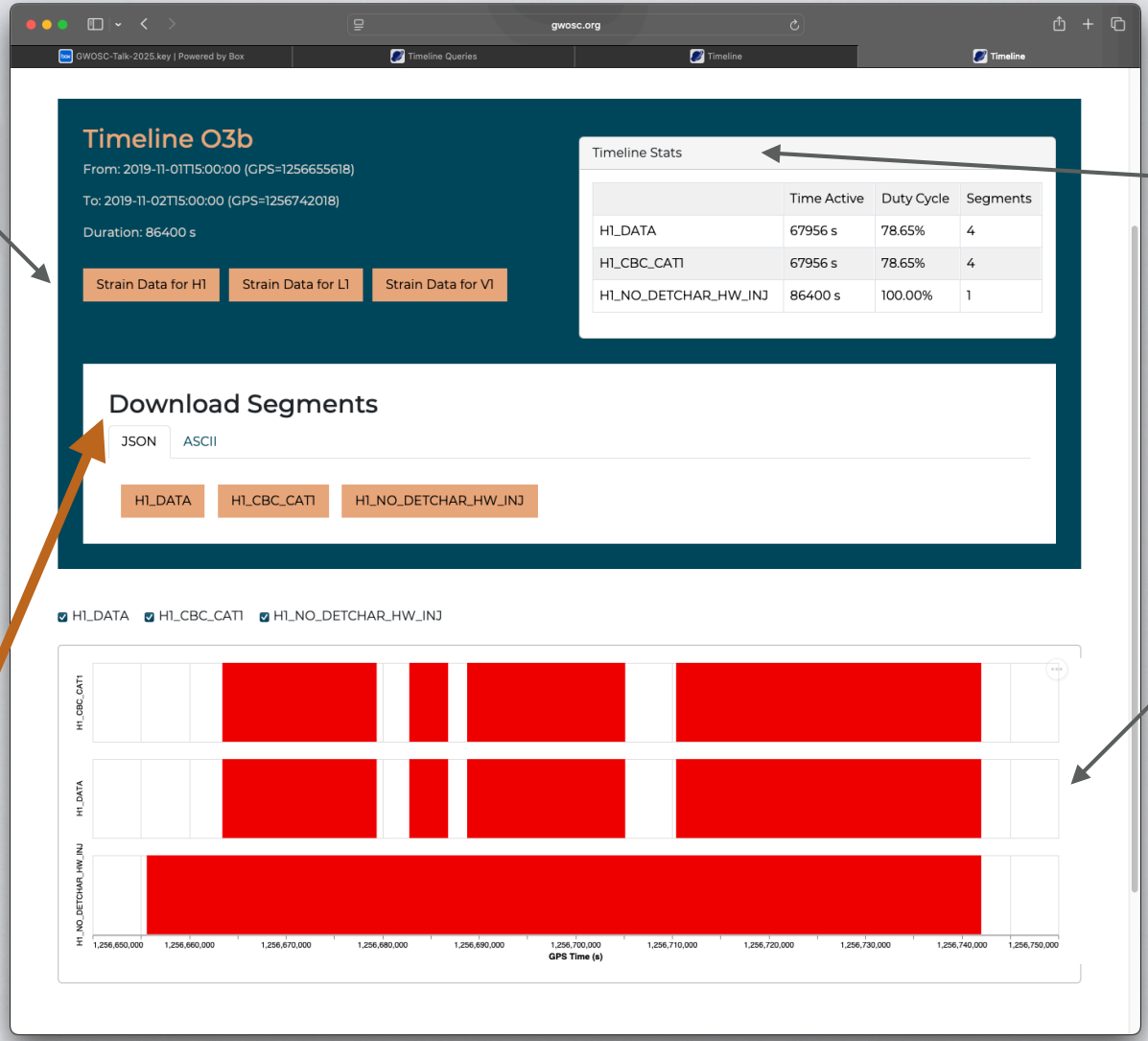
These are times when NO specific hardware injection has been added

PLOTS OF SELECTED DATA QUALITY

Portals to Strain Data

Select individual data quality flag to view list of start/end times for all segments in this interval;

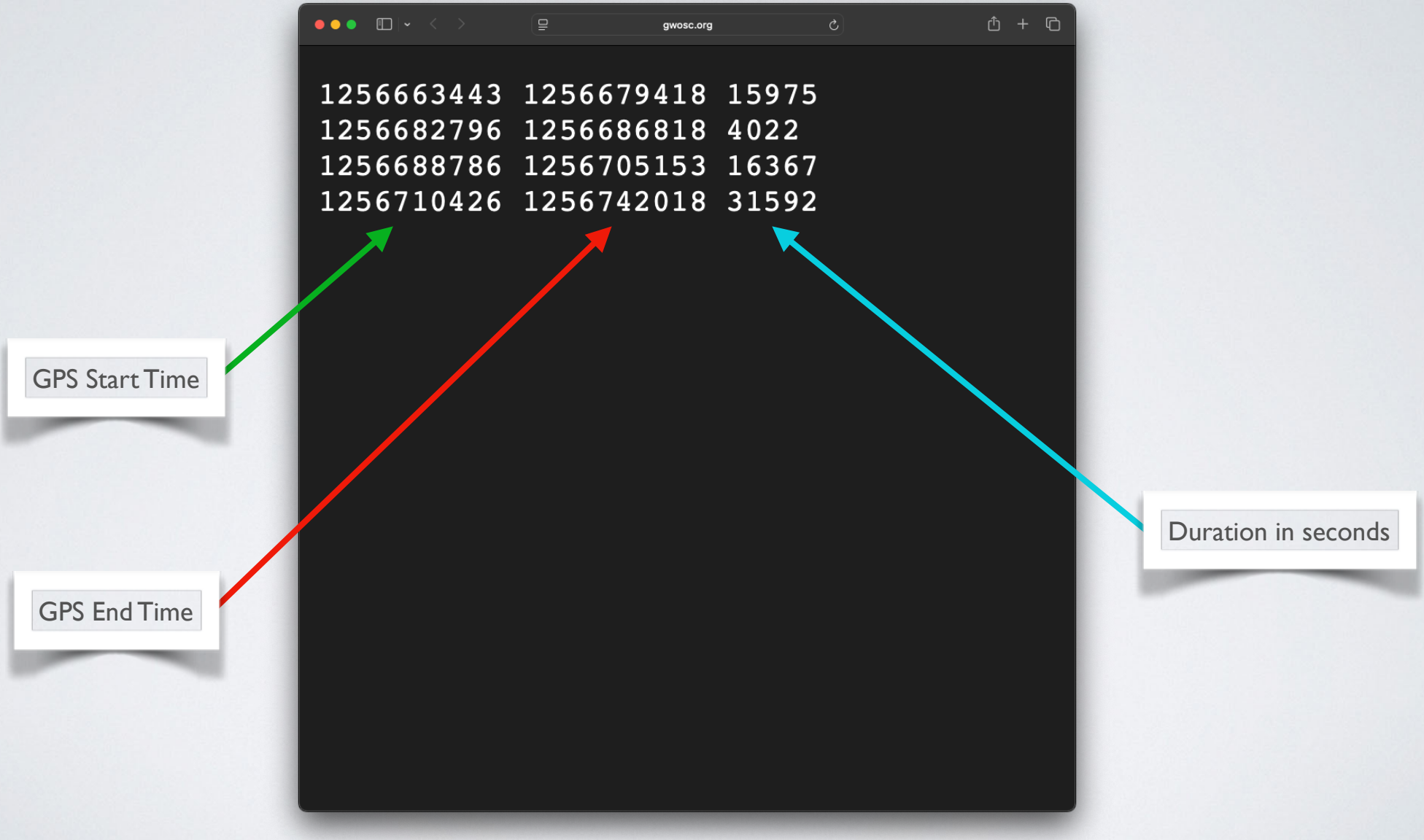
Lets look at the **ASCII** output for **H1_DATA**.



Statistics for timelines: No DETCHAR and No CBC_CAT1 cuts!

Graphs of selected data quality flags

EXAMPLE SEGMENT LIST (H1_DATA)



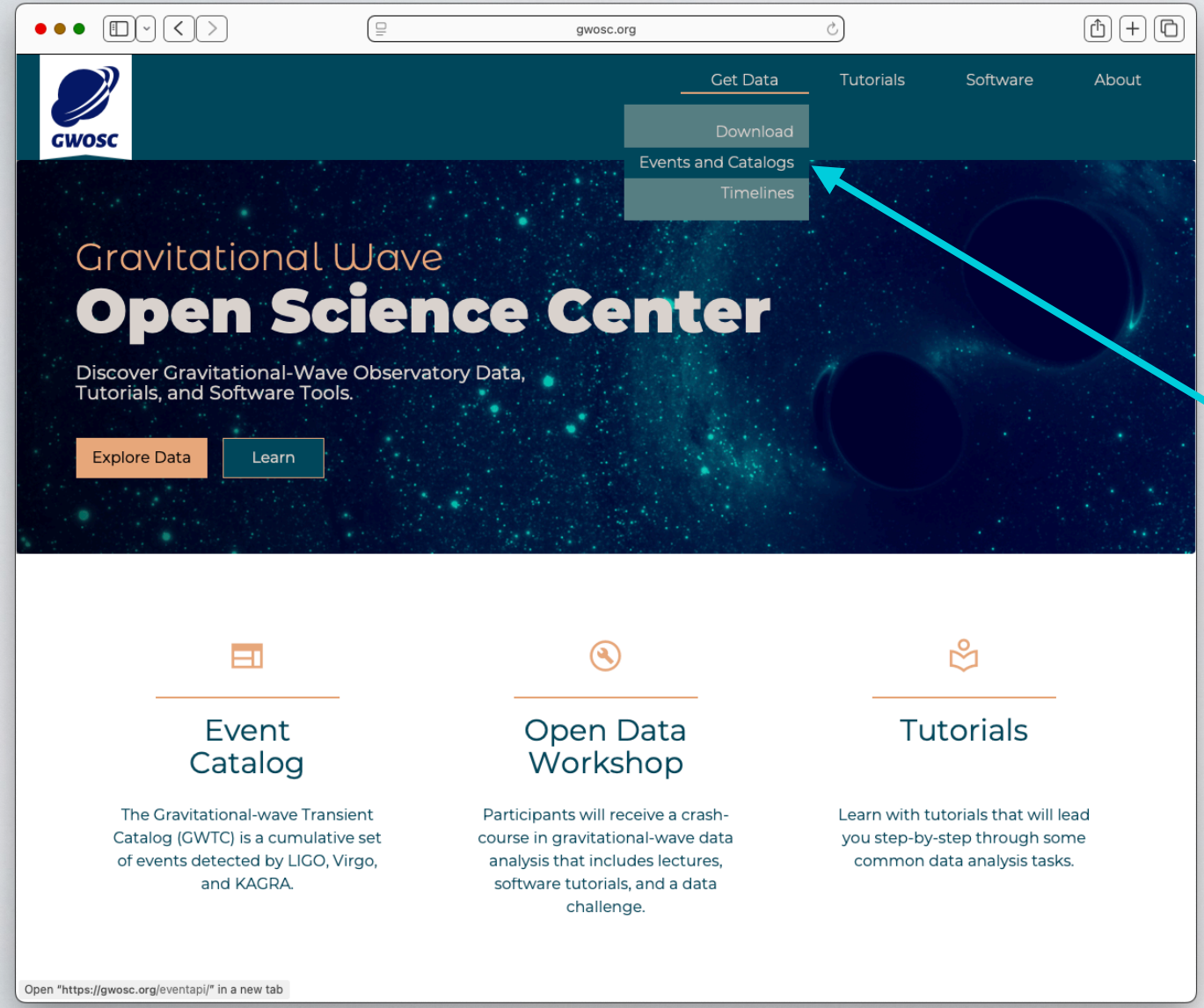
EVENTS AND CATALOGS

THE EVENT PORTAL

EVENT PORTAL

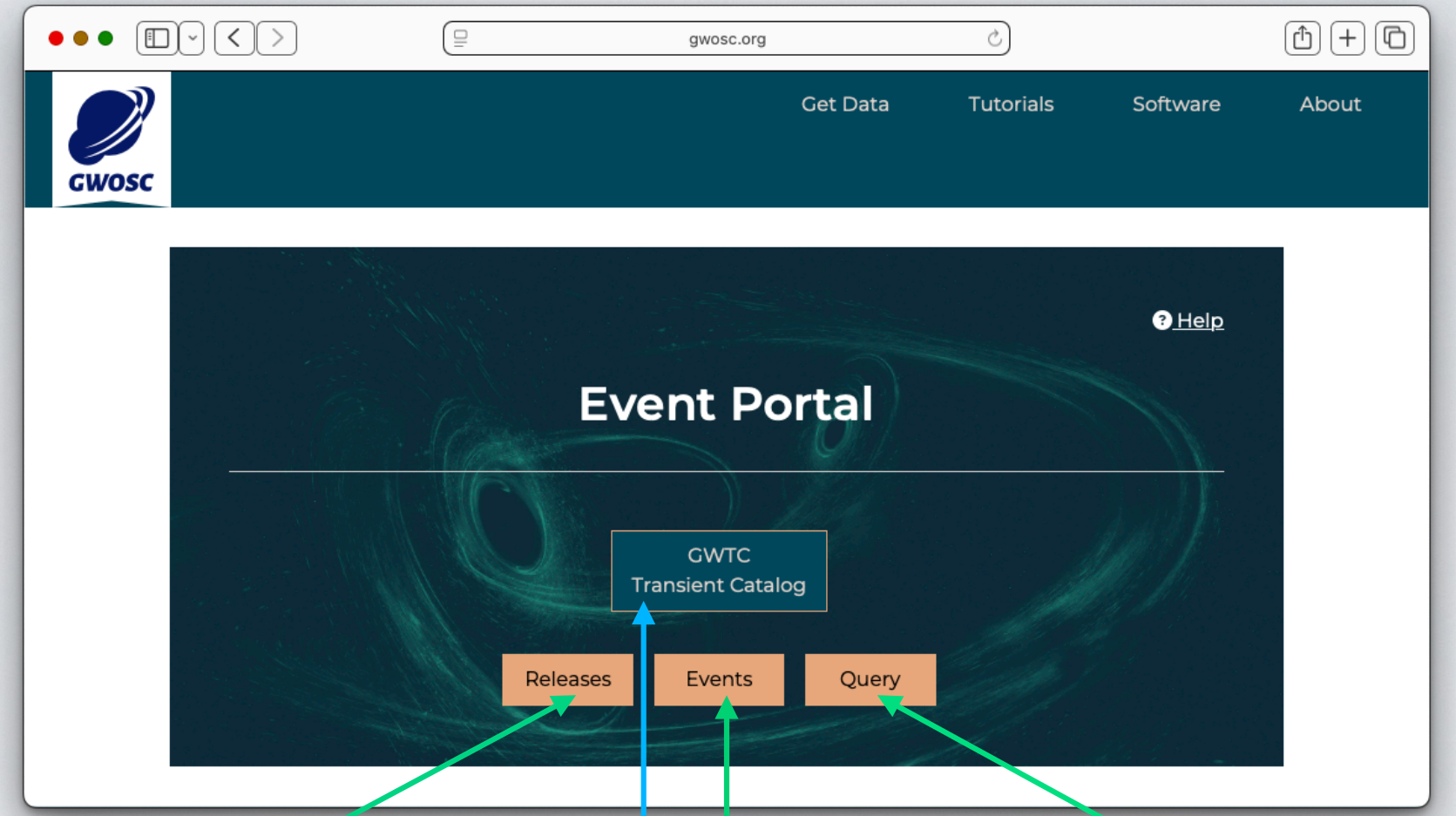
- The Event Portal is the gateway to events and catalogs
- Catalogs are groupings of events typically related by the observational run they were found in. They are also referred to as releases.
- Some catalogs have marginal events where not all criteria for confidence were met by searches.
- The GWTC Transient Catalog captures all confident events found by the LIGO/Virgo/KAGRA collaborations.
- We have started a program for including catalogs from the broader community (Community Catalogs).

NAVIGATING THE EVENT PORTAL



To access the Event Portal, click **Events and Catalogs** menu option under Get Data

EVENT PORTAL FEATURES



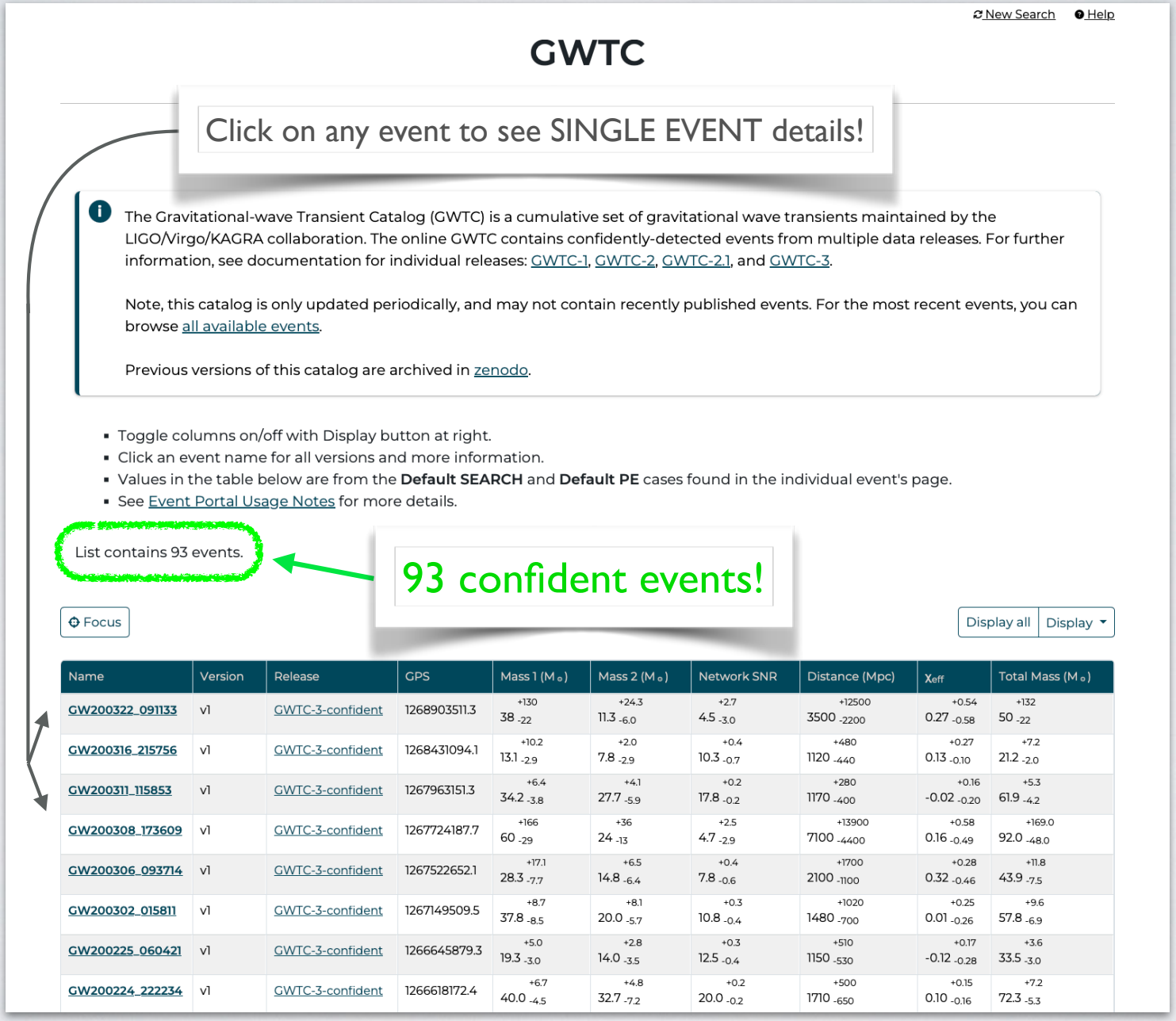
Click for Catalogs/Releases

Click for LVK confident detection Events

Click for ALL Events

Click for Query Form

GWTC TRANSIENT CATALOG



New Search Help

GWTC

Click on any event to see SINGLE EVENT details!

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.

93 confident 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}	$-0.12^{+0.17}_{-0.28}$	$33.5^{+3.6}_{-3.0}$
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}	$0.10^{+0.15}_{-0.16}$	$72.3^{+7.2}_{-5.3}$

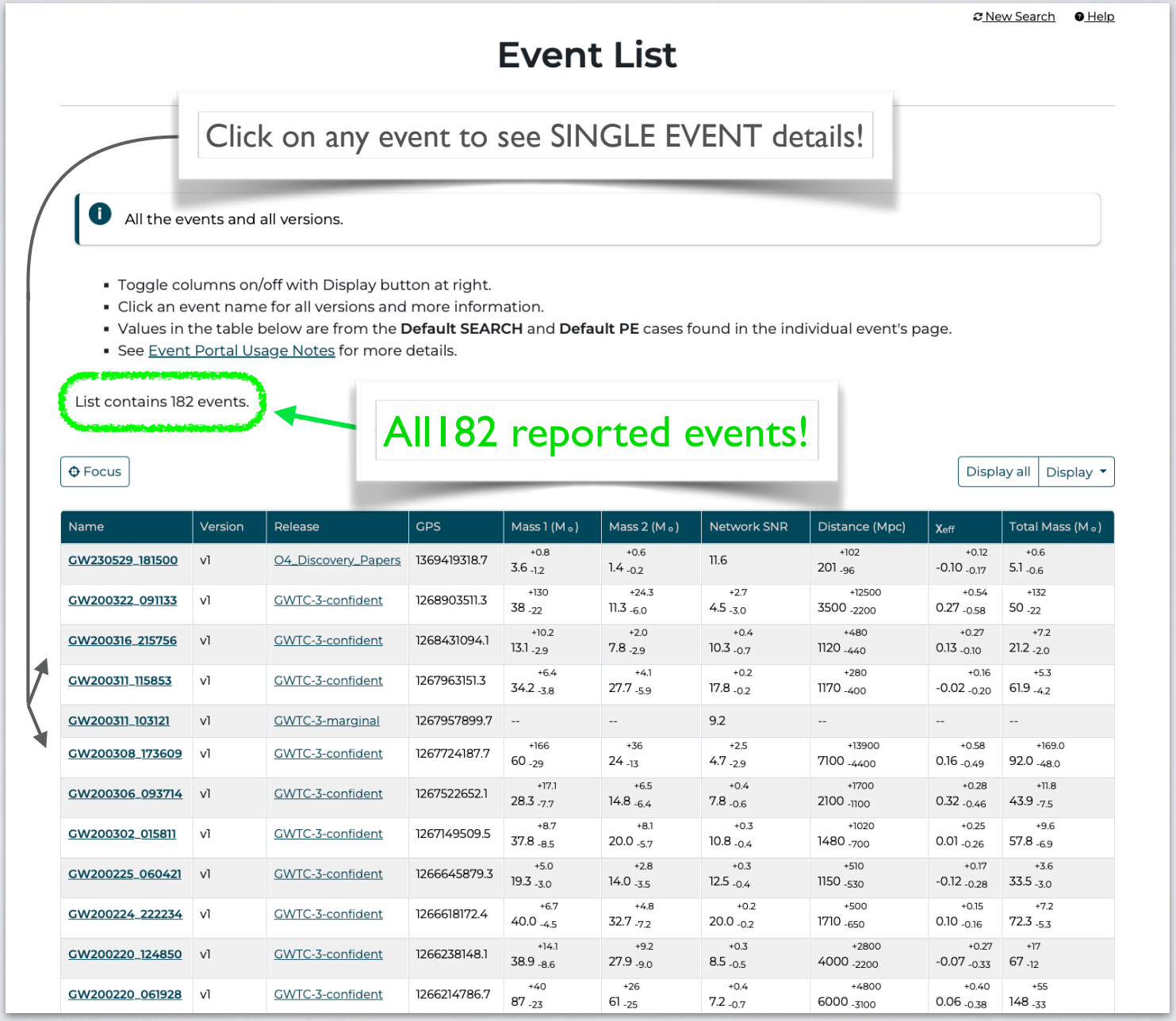
RELEASES

Release List

Click on any Release Name to see Table of Events in Catalog

Release Name	Description
GWTC	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.
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 candidates 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.
GWTC-2.1-auxiliary	This release/list/table contains candidates from GWTC-2 which, based on the [updated] analysis presented in the GWTC-2.1 catalog paper [https://arxiv.org/abs/2108.01045], do not satisfy the requirements/criteria for inclusion in the GWTC-2.1-confident or GWTC-2.1-marginal releases.
GWTC-2.1-confident	Confident events from the O3A observation run for LIGO and Virgo, as described in the GWTC-2.1 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.
GWTC-2.1-marginal	Marginal candidates from the O3A observation run for LIGO and Virgo, as described in the GWTC-2.1 catalog paper. Details and additional data products are linked from the documentation page.
GWTC-3-confident	Confident events from the O3b observing run for LIGO and Virgo, as described in the GWTC-3 catalog paper. These candidate events have a probability of astrophysical origin (probability of being a gravitational-wave signal versus being instrumental noise) assuming a compact binary (such as a binary black hole, neutron star-black hole binary or binary neutron star) coalescence source of greater than 0.5 based upon results of at least one of the search pipelines. 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.

EVENTS



New Search Help

Event List

Click on any event to see SINGLE EVENT details!

All the events and all versions.

- 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 182 events.

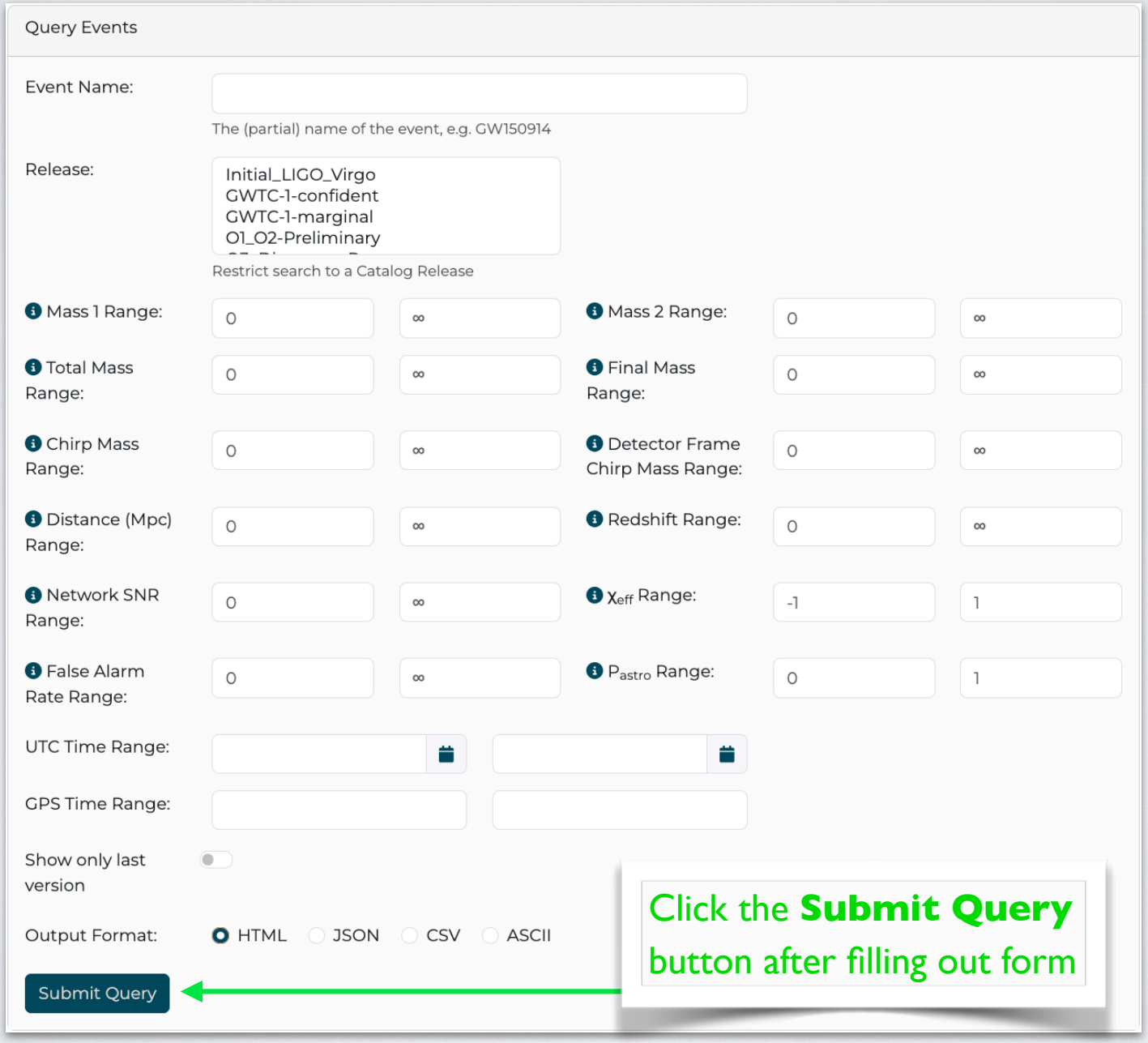
All 182 reported events!

Focus

Display all | Display

Name	Version	Release	GPS	Mass 1 ($M_\odot$)	Mass 2 ($M_\odot$)	Network SNR	Distance (Mpc)	χ_{eff}	Total Mass ($M_\odot$)
GW230529_181500	v1	O4_Discovery_Papers	1369419318.7	$3.6^{+0.8}_{-1.2}$	$1.4^{+0.6}_{-0.2}$	11.6	201^{+102}_{-96}	$-0.10^{+0.12}_{-0.17}$	$5.1^{+0.6}_{-0.6}$
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}	$-0.02^{+0.16}_{-0.20}$	$61.9^{+5.3}_{-4.2}$
GW200311_103121	v1	GWTC-3-marginal	1267957899.7	--	--	9.2	--	--	--
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}

QUERY FORM

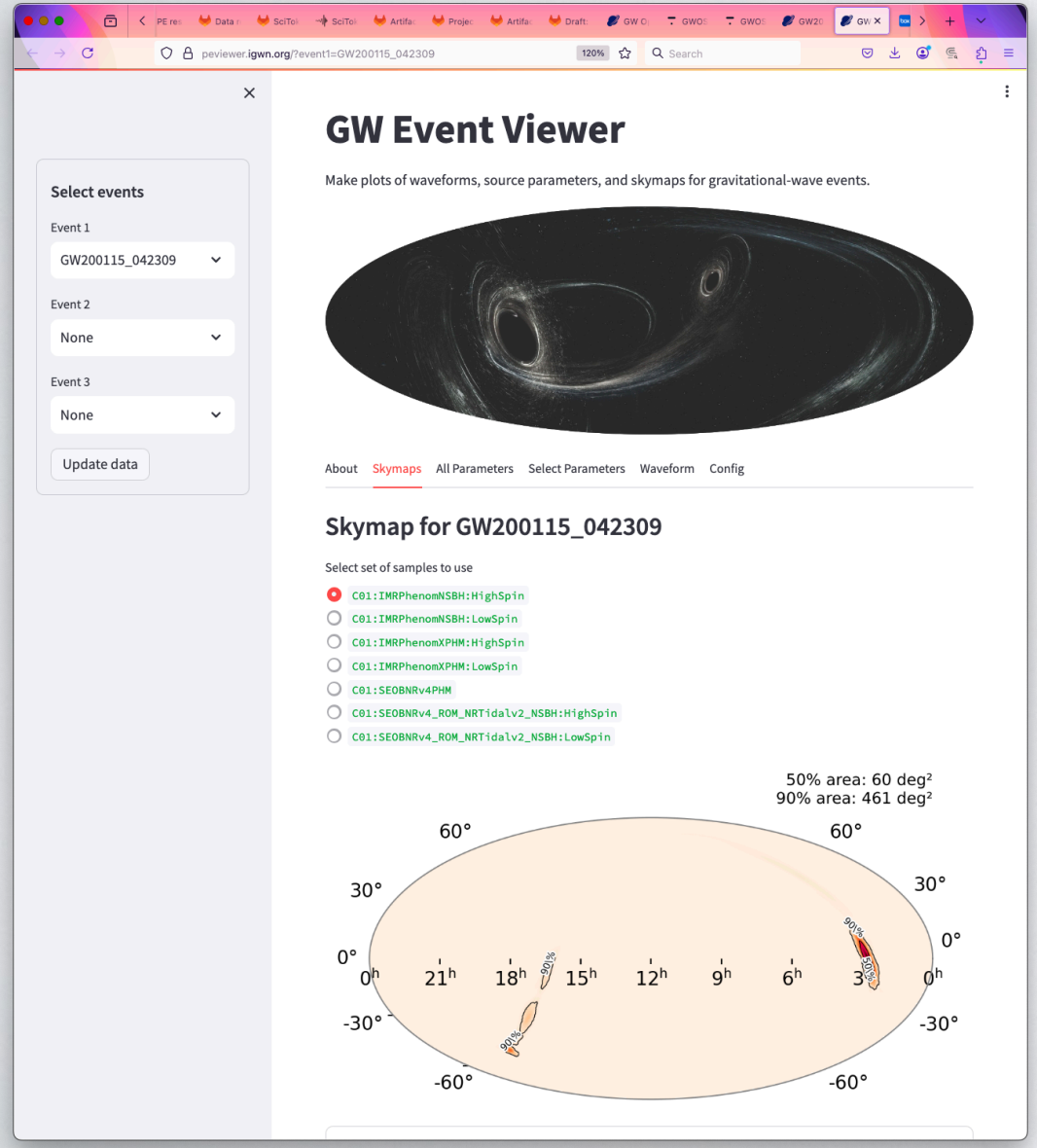

Query Events
Event Name:
The (partial) name of the event, e.g. GW150914
Release:
Initial_LIGO_Virgo
GWTC-1-confident
GWTC-1-marginal
O1_O2-Preliminary
Restrict search to a Catalog Release
Mass 1 Range:
0
∞
Mass 2 Range:
0
∞
Total Mass Range:
0
∞
Final Mass Range:
0
∞
Chirp Mass Range:
0
∞
Detector Frame Chirp Mass Range:
0
∞
Distance (Mpc) Range:
0
∞
Redshift Range:
0
∞
Network SNR Range:
0
∞
χeff Range:
-1
1
False Alarm Rate Range:
0
∞
Pastro Range:
0
1
UTC Time Range:
GPS Time Range:
Show only last version
Output Format:
HTML
JSON
CSV
ASCII
Submit Query
Click the Submit Query button after filling out form

SINGLE EVENT PAGE

Lots of information in one place

- Metadata about event
- All search results
- All parameter estimation results
- Links to PE samples and skymaps
- Q-Transform plots centered on event
- Strain data downloads
- Interactive Plotting via **Event Viewer**

GRAVITATIONAL WAVE EVENT VIEWER



Visualize Various Aspects of Events

- Select Events
- Skymaps
- Parameters (all or subset)
- Waveforms

https://peviewer.igwn.org/

COMMUNITY CATALOGS

Community Catalog Information

The GWOSC Event Portal provides access to a database of known gravitational-wave events. Before 2025, the database only included events published by the LIGO/Virgo/KAGRA (LVK) collaboration. Here, we set out guidelines for how catalogs from authors outside the LVK collaboration can be added to the Event Portal database. By taking this step, we hope to better reflect the current state of knowledge about gravitational-wave transients, and so better serve the scientific community.

Publishing Community Catalogs on GWOSC

You can learn more about the possibility to add your community catalogs to the Event Portal in the GWOSC Community Catalogs Guidelines document.

Community Catalogs development details are provided on GitHub where the JSON schema is specified, as well as test codes and notebooks for validation of the JSON file format. This provides the standardization for sharing a new community catalog with GWOSC for injestion, when the criteria outlined in the guidelines are satisfied.

Current List of Community Catalogs

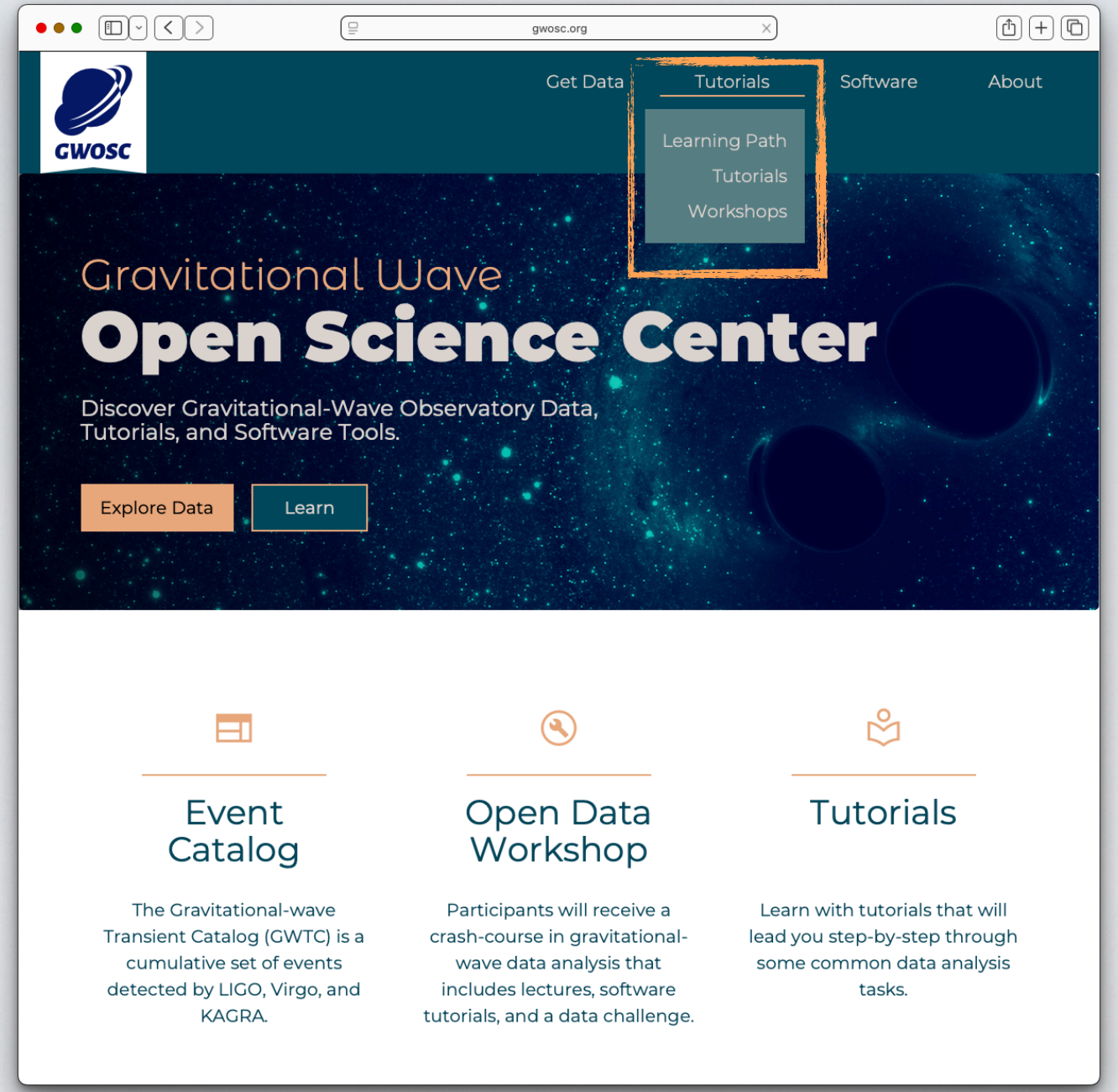
Release Name	Description
IAS-O3a	The IAS-O3a catalog contains 42 binary black hole mergers in the public data from the first half of the third observing run (O3a) of advanced LIGO and advanced Virgo. Of these, 10 were reported there for the first time. Details and additional data products are linked from the documentation page.

WHAT ARE COMMUNITY CATALOGS

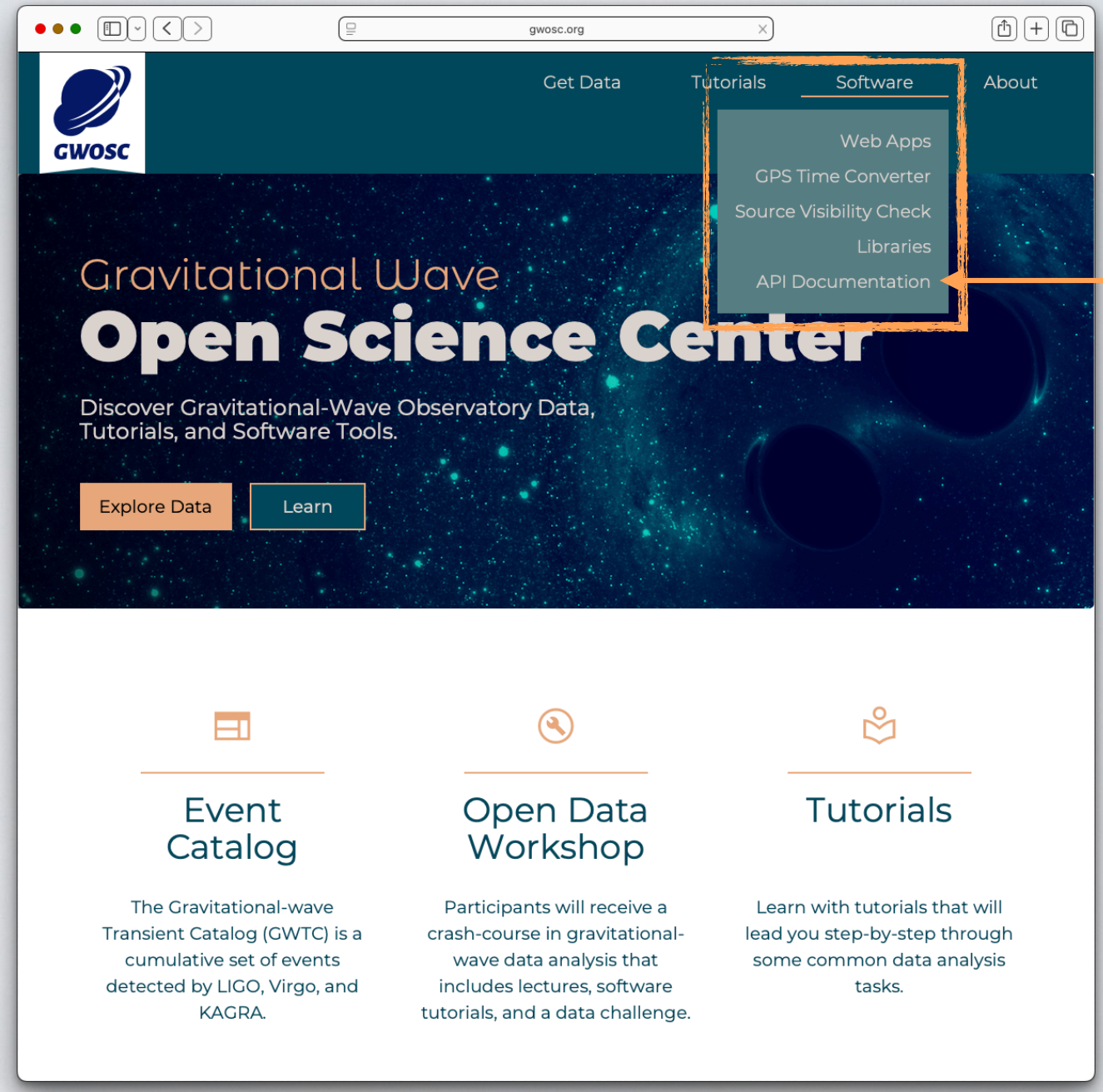
- Catalogs by authors outside of the LVK collaboration that are included on GWOSC
  - (see https://gwosc.org/CommCatalogs/CommCatInfo/)
- Community Catalogs are carefully vetted using the criteria listed in the *Community Catalog Guidelines document:*
  - Goal is to include the full set of GW discoveries available in the scientific literature.
  - It is not meant to include every re-analysis; instead to focus on work that discovers previously unknown astrophysical transients.
  - In general, catalogs that are added to the Event Portal should be published in a respected peer-reviewed, scientific journal.
  - (see https://dcc.ligo.org/LIGO-M2500012/public *for guideline details)*
- Currently one (IAS-O3a) community catalog, but have plans for more in the future.

TUTORIALS, SOFTWARE & MORE

TUTORIALS MENU



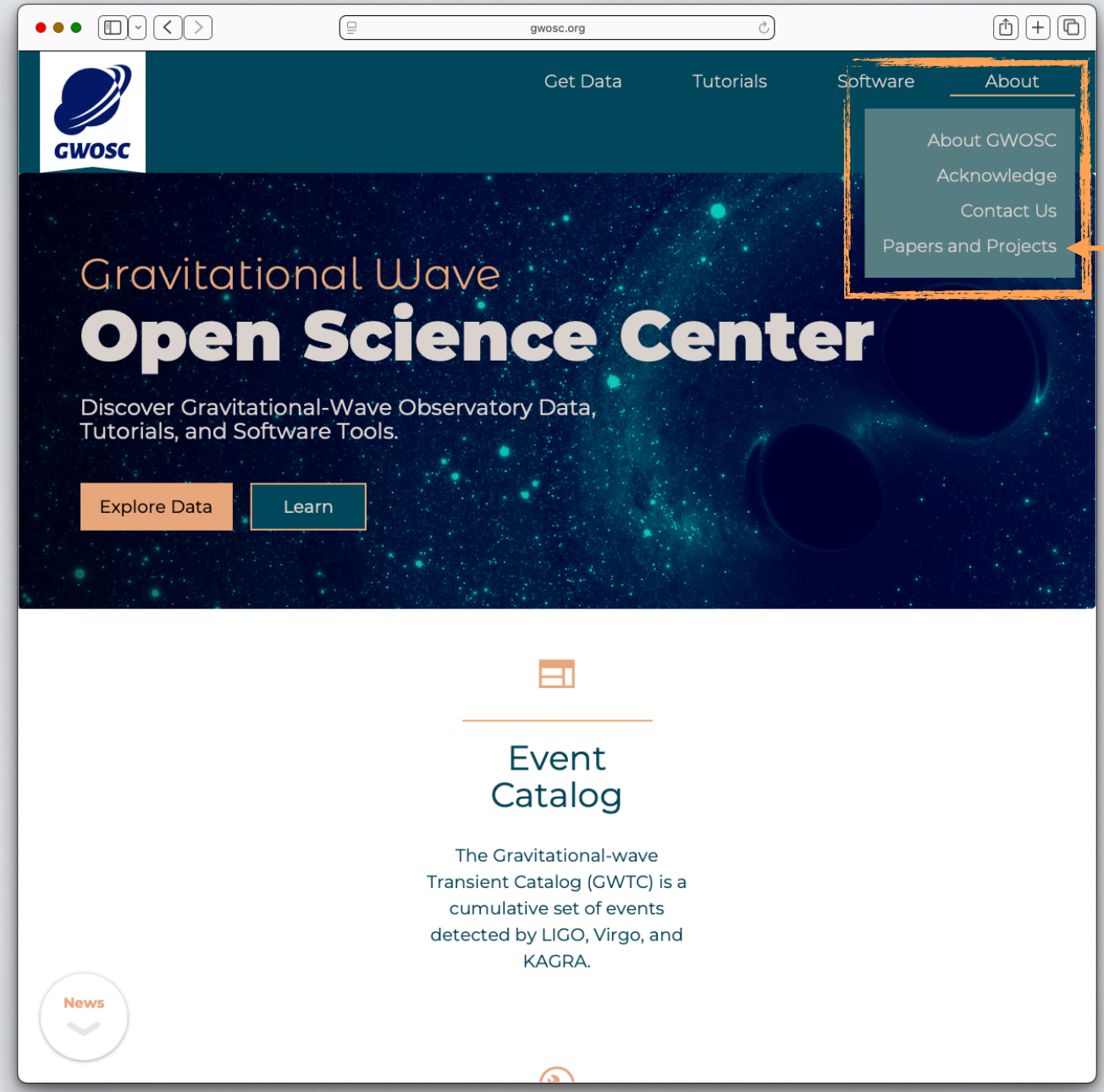
SOFTWARE



Programmatic interface to the data!

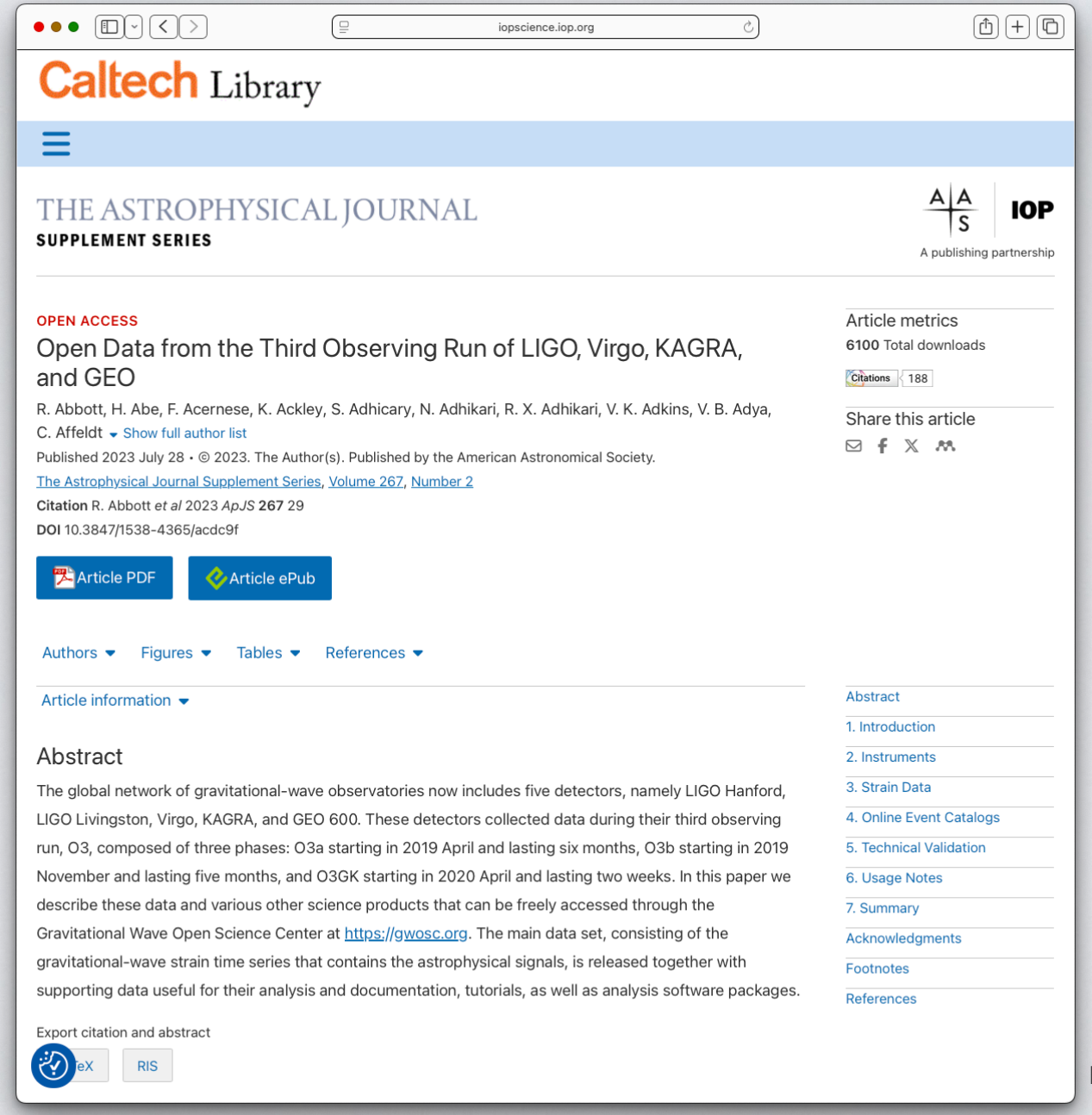
PROGRAMMATIC ACCESS TO DATA

ABOUT



Papers about GWOSC and much more!

LATEST O3B OPEN DATA PAPER



DOI 10.3847/1538-4365/acdc9f

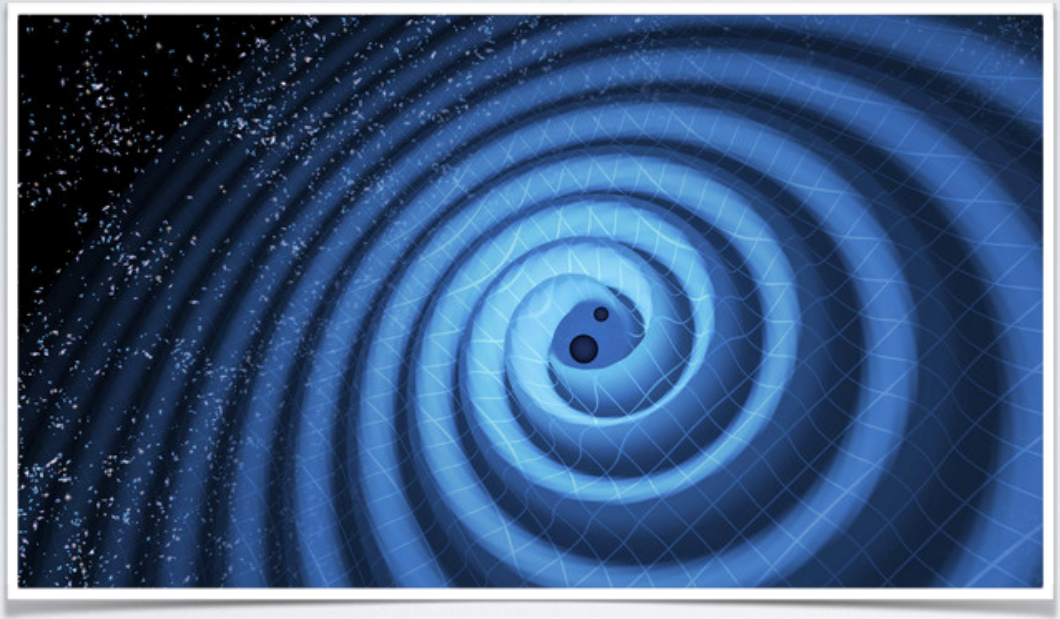
“I was born not knowing and have had only a little time to change that here and there.”

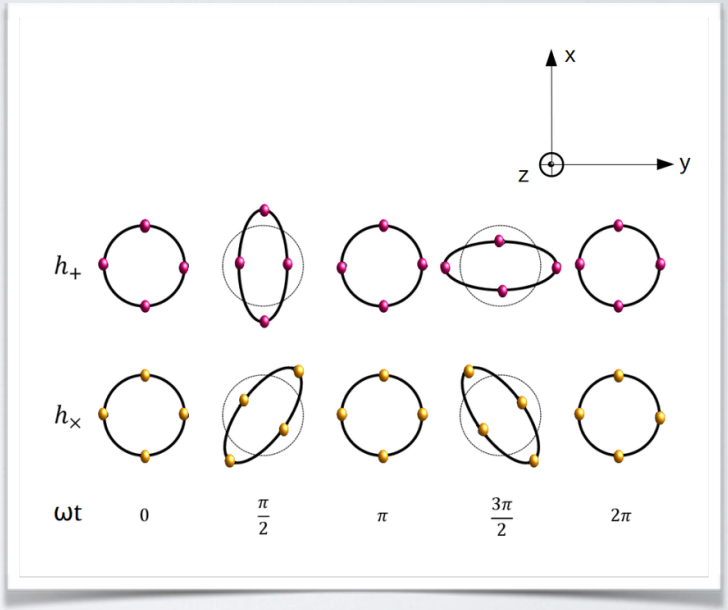
– Richard P. Feynman

BONUS SLIDES

FOR YOUR SPARE TIME

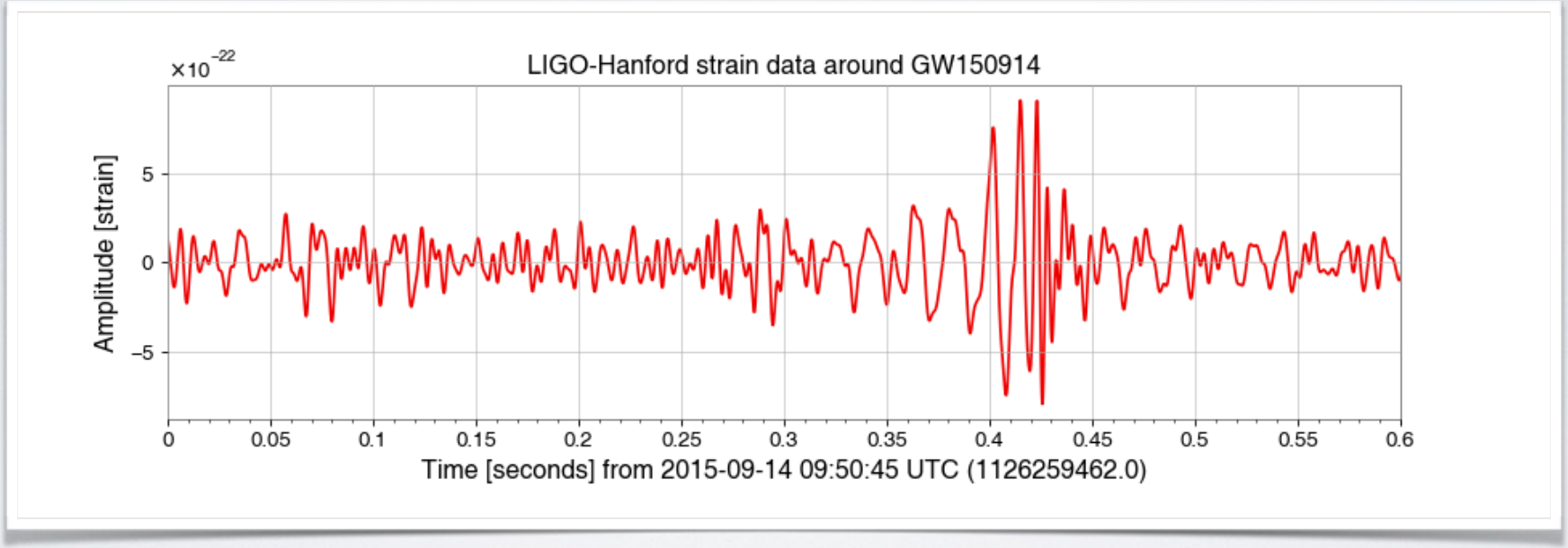
WHAT ARE GRAVITATIONAL WAVES?





- Gravitational waves are **ripples in the fabric of spacetime**, illustrated in the left figure.
- Gravitational waves **travel at the speed of light** in a vacuum.
- Gravitational waves have **two fundamental polarizations** states called "plus" and "cross", denoted by h_+ and $h_\times$ in the right figure.
  - The plus (+) polarization, the circle stretches vertically and squeezes horizontally.
  - The cross (×) polarization, the stretching and squeezing happens at 45° angles relative to the plus.
  - If the detector arm are along the x and y directions and the wave travels in the z direction, only the h_+ polarization would be measured by the gravitational wave detector.

HOW GRAVITATIONAL WAVES ARE DETECTED



- Gravitational wave detectors experience the linear combination of these polarizations projected along the detector arms.
- The strain measured by the a gravitational wave detector is given by the change in length divided by the length of the detector's arms (*notice how small this is in the plot above - a few times* 10^{-22}).
- The gravitational signal measured by the LIGO-Hanford detector for the first detection (GW150914) is shown.
- The LIGO Livingston arms are sensitive to roughly the same polarization states but typically have a different time of arrival based on the position of the source on the sky.
    - NOTE: This detection resulted in the Nobel Prize in Physics (2017).
- This measured polarization state is the strain data provided on GWOSC.

WHY STUDY GRAVITATIONAL WAVES

Studying **gravitational waves** opens a **new way/window to observe the universe**, beyond light (electromagnetic waves), neutrinos, or cosmic rays:

- **New Information**: Gravitational waves carry information about events that **don't emit light** or whose light is hidden, like the collision of black holes. Traditional telescopes can't "see" these.
- **Testing Einstein's Theory**: They allow us to **test general relativity** in extreme conditions (like near black holes and neutron stars) where no other tests are possible.
- **Understanding Cosmic Events**: Gravitational waves reveal details about **cataclysmic events** — like black hole mergers, neutron star collisions, non-axisymmetric pulsars, supernovae, and even the Big Bang.
- **Probing the Early Universe**: Light-based telescopes can't look back earlier than about 380,000 years after the Big Bang (CMB), but gravitational waves could carry information from much **earlier times** — possibly just after the Big Bang.
- **Discovering the Unknown**: Just like radio waves led to discovering pulsars and X-rays led to finding black hole candidates, gravitational wave astronomy might **reveal phenomena we haven't imagined yet**.
- **Interdisciplinary Advances**: Multi-messenger astronomy / Developing the technology to detect gravitational waves (like LIGO and Virgo) pushes boundaries in **lasers, optics, quantum mechanics, data science, and materials science**.
- **Mature a User Community:** Researchers, Students, Citizen Scientists, Educators, and you.