GWOSC: Gravitational Wave Open Science Center

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GWOSC

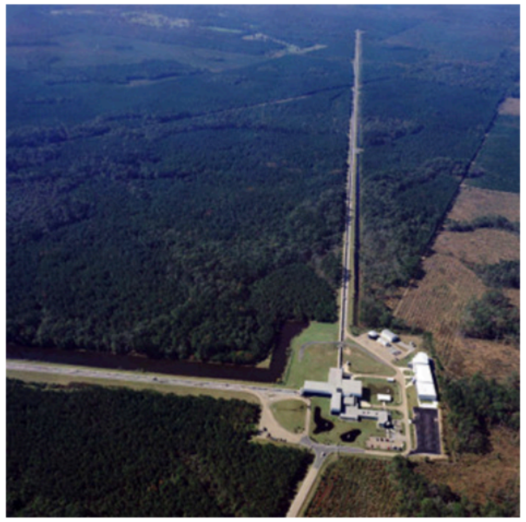
Gravitational Wave Open Science Center

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

Data▾ Software▾ Online Status▾ 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)

Get started!

LIGO/Virgo alerts began April 2, 2019

Download data

Join the email list

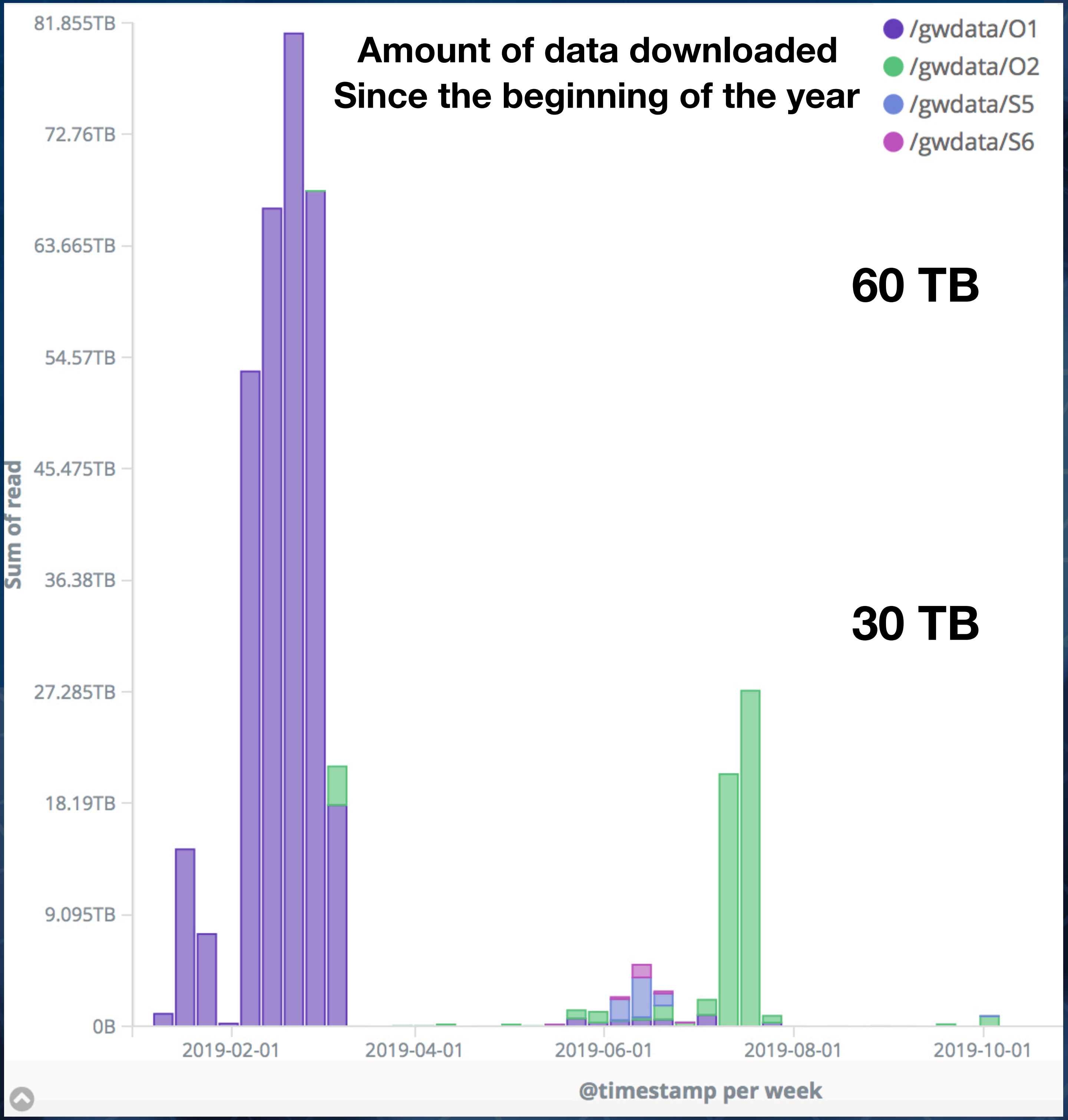
Open Data Workshop #2: Videos & Tutorials

Importance of Open Science:
- Public owns the data
- Maximize discovery
- Multi-messenger astronomy
- Wider community

GWOSC Impact

Examples of projects using GWOSC data: https://www.gw-openscience.org/projects/

- ✓ Scientific papers (about 80 at the moment) —> *see talk by Frédérique Marion on the use of Open Data*
- ✓ Pioneer Academics student projects
- ✓ iPhone App: Gravitational Wave Events
- ✓ Online Course
- ✓ Art installation



GWOSC releases

- Open data can be found at https://www.gw-openscience.org
- Two different types of data release:

Gravitational wave data surrounding discoveries

Data taken during a whole observation run

- Some releases:

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

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

GWOSC bulk data

Gravitational Wa…

🏠 Data ▾ Software ▾ Online Status ▾ About GWOS…

- Strain Data
- Catalogs
- Timelines

…tational Wave Open…
…observatories, alon…

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(Credits: C. Gray)

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LIGO and Virgo Data

Click for data usage notes **Please Read This First!**

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

Data for Events

Events

Large Data Sets for High Performance Computing

For users of computing clusters, CernVM-FS is the preferred method to access large data sets:

CernVM FS

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

-> Once you have installed and configured CernVM-FS client, you will be able to access data from these observation runs as files in subdirectories on your computer

O2 Data Release

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

4KHz Data | 16KHz Data | Documents | Timeline

Scrolling down you get the data for O1, S5 and S6

GWTC-1: Gravitational-Wave Transient Catalog of Compact Binary Mergers

- https://www.gw-openscience.org/catalog/
- 11 confident detection + 14 marginal triggers
- Strain data + documentation + auxiliary data products (Skymaps, Parameter Estimation Samples,…)

JSON Parameter Table

Show/hide columns

SORT: PRIMARY MASS (M_SUN) ↑

Event	Primary mass (M_sun)	Secondary mass (M_sun)	Effective inspiral spin	chirp mass (M_sun)	Final spin	Final mass (M_sun)	Luminosity distance (Mpc)	GPS time (s)
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$-0.01^{+0.12}_{-0.13}$	$28.6^{+1.6}_{-1.5}$	$0.69^{+0.05}_{-0.04}$	$63.1^{+3.3}_{-3.0}$	430^{+150}_{-170}	1126259462.4
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$0.04^{+0.28}_{-0.19}$	$15.2^{+2.0}_{-1.1}$	$0.67^{+0.13}_{-0.11}$	$35.7^{+9.9}_{-3.8}$	1060^{+540}_{-480}	1128678900.4
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$0.18^{+0.20}_{-0.12}$	$8.9^{+0.3}_{-0.3}$	$0.74^{+0.07}_{-0.05}$	$20.5^{+6.4}_{-1.5}$	440^{+180}_{-190}	1135136350.6
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$-0.04^{+0.17}_{-0.20}$	$21.5^{+2.1}_{-1.7}$	$0.66^{+0.08}_{-0.10}$	$49.1^{+5.2}_{-3.9}$	960^{+430}_{-410}	1167559936.6
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$0.03^{+0.19}_{-0.07}$	$7.9^{+0.2}_{-0.2}$	$0.69^{+0.04}_{-0.04}$	$17.8^{+3.2}_{-0.7}$	320^{+120}_{-110}	1180922494.5
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$0.36^{+0.21}_{-0.25}$	$35.7^{+6.5}_{-4.7}$	$0.81^{+0.07}_{-0.13}$	$80.3^{+14.6}_{-10.2}$	2750^{+1350}_{-1320}	1185389807.3
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$0.07^{+0.16}_{-0.16}$	$25.0^{+2.1}_{-1.6}$	$0.70^{+0.08}_{-0.09}$	$56.4^{+5.2}_{-3.7}$	990^{+320}_{-380}	1186302519.8
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3^{+2.9}_{-4.1}$	$0.07^{+0.12}_{-0.11}$	$24.2^{+1.4}_{-1.1}$	$0.72^{+0.07}_{-0.05}$	$53.4^{+3.2}_{-2.4}$	580^{+160}_{-210}	1186741861.5
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$0.00^{+0.02}_{-0.01}$	$1.186^{+0.001}_{-0.001}$	≤ 0.89	≤ 2.8	40^{+10}_{-10}	1187008882.4
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$-0.09^{+0.18}_{-0.21}$	$26.7^{+2.1}_{-1.7}$	$0.67^{+0.07}_{-0.08}$	$59.8^{+4.8}_{-3.8}$	1020^{+430}_{-360}	1187058327.1
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4^{+6.3}_{-7.1}$	$0.08^{+0.20}_{-0.22}$	$29.3^{+4.2}_{-3.2}$	$0.71^{+0.08}_{-0.10}$	$65.6^{+9.4}_{-6.6}$	1850^{+840}_{-840}	1187529256.5

GWOSC Tutorials

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

Open Data Workshops Web Courses:

- about 5 hours of lecture (slides + lecture videos)
- Data analysis programming exercises (jupyter notebooks)

Gravitational Wave Open Data Workshop Web Course (2019)

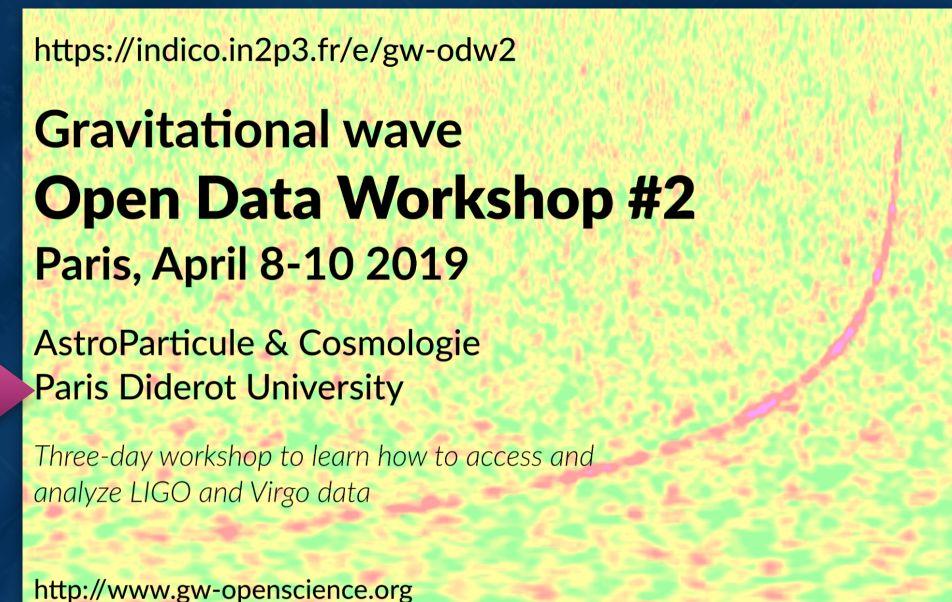
Lecture videos and tutorials from 2019 workshop

Course Material

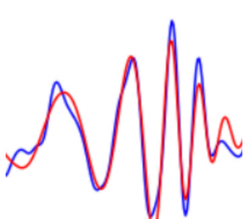
Gravitational Wave Open Data Workshop Web Course (2018)

Lecture videos and tutorials from 2018 workshop

Course Material



Guide to LIGO-Virgo detector noise



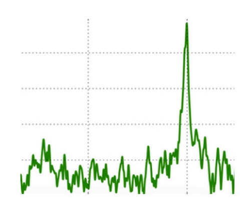
Code from "A guide to LIGO-Virgo detector noise and extraction of transient gravitational wave signals"

Code used to produce paper: github

Jupyter notebook to illustrate methods used to produce key figures: github | Google Colab | mybinder

Basic data analysis applied to GW events

Binary Black Hole Events



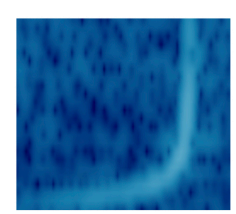
Use matched filtering to find signals hidden in noise.

Run: Azure | mybinder (Beta)

View: GW150914 | LVT151012 | GW151226 | GW170104

Download: file with data | Jupyter notebook | Python script

Quickview Notebook

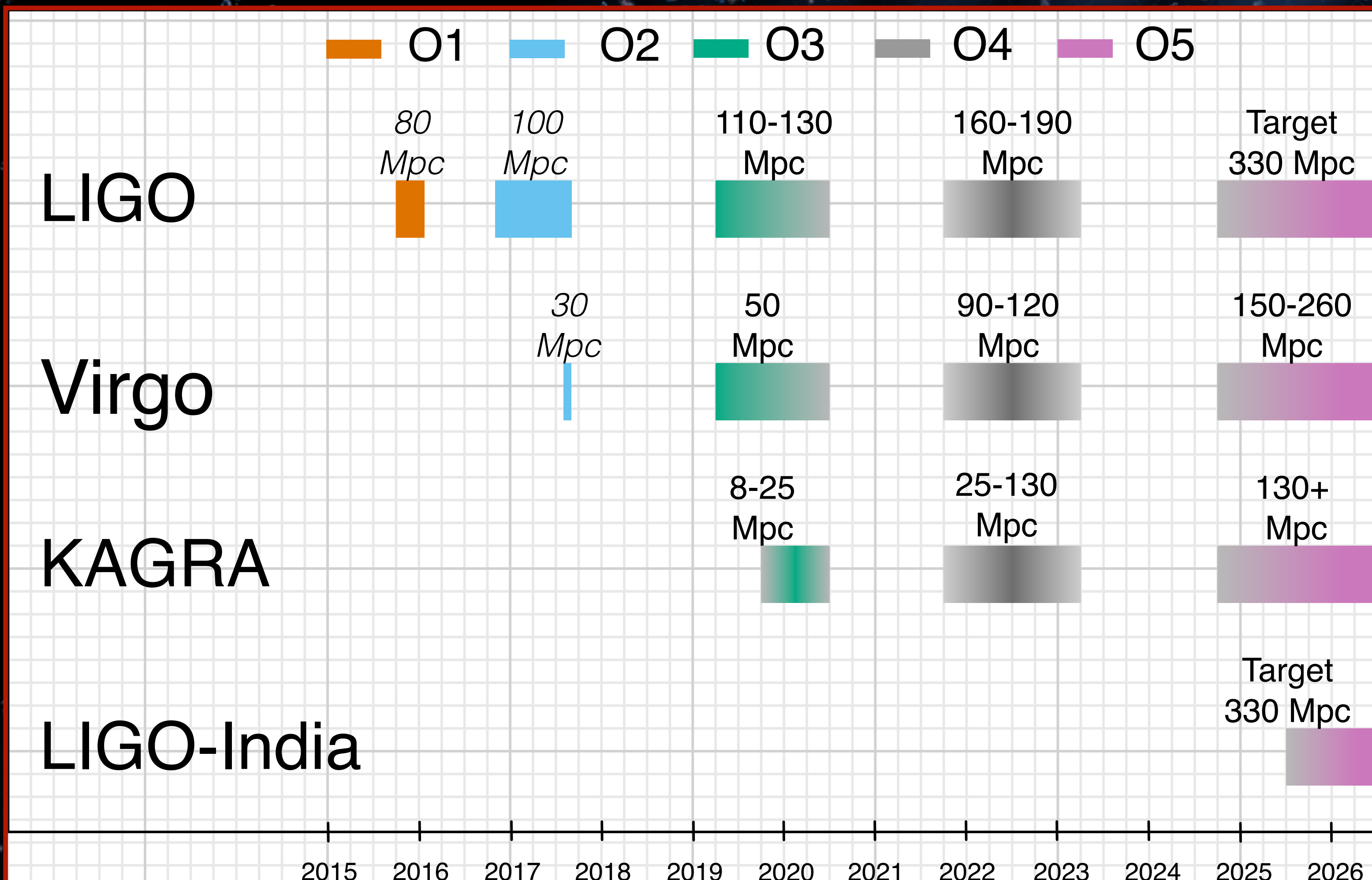


Make summary plots for a short segment of strain data.

Run: Google Colab | mybinder

Download: github

Near future



Third Observing run (O3) started in Apr 2019 (—> *see talk by Ed Porter*)

- ✓ Detection candidates: 33
  - ✓ Great part BBH candidates
  - ✓ 3 BNS candidates
  - ✓ 4 NSBH candidates

arXiv:1304.0670

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	2^{+8}_{-2}	0^{+19}_{-0}	15^{+19}_{-10}
O4	HLVK	8^{+42}_{-7}	2^{+94}_{-2}	68^{+81}_{-38}

The number of expected detections will reach O(100) in the near future

Near future for GWOSC (I)

- Data Management Plan=>https://dcc.ligo.org/LIGO-M1000066/public

Near future for GWOSC (II)

> **The number of detections will explode—> new features necessary**

- Queryable database: complex queries (name, conditions on parameters, …)
- API to allow an interface with the database —> increase automatisation
- New interface more user-friendly containing basic plots (e.g. spectrograms)
- More info in the database to trace the provenance of the data
- Keep track of multiple versions for the same event
- Keep track of multiple catalogs

> **Products to be released in addition to the strain**

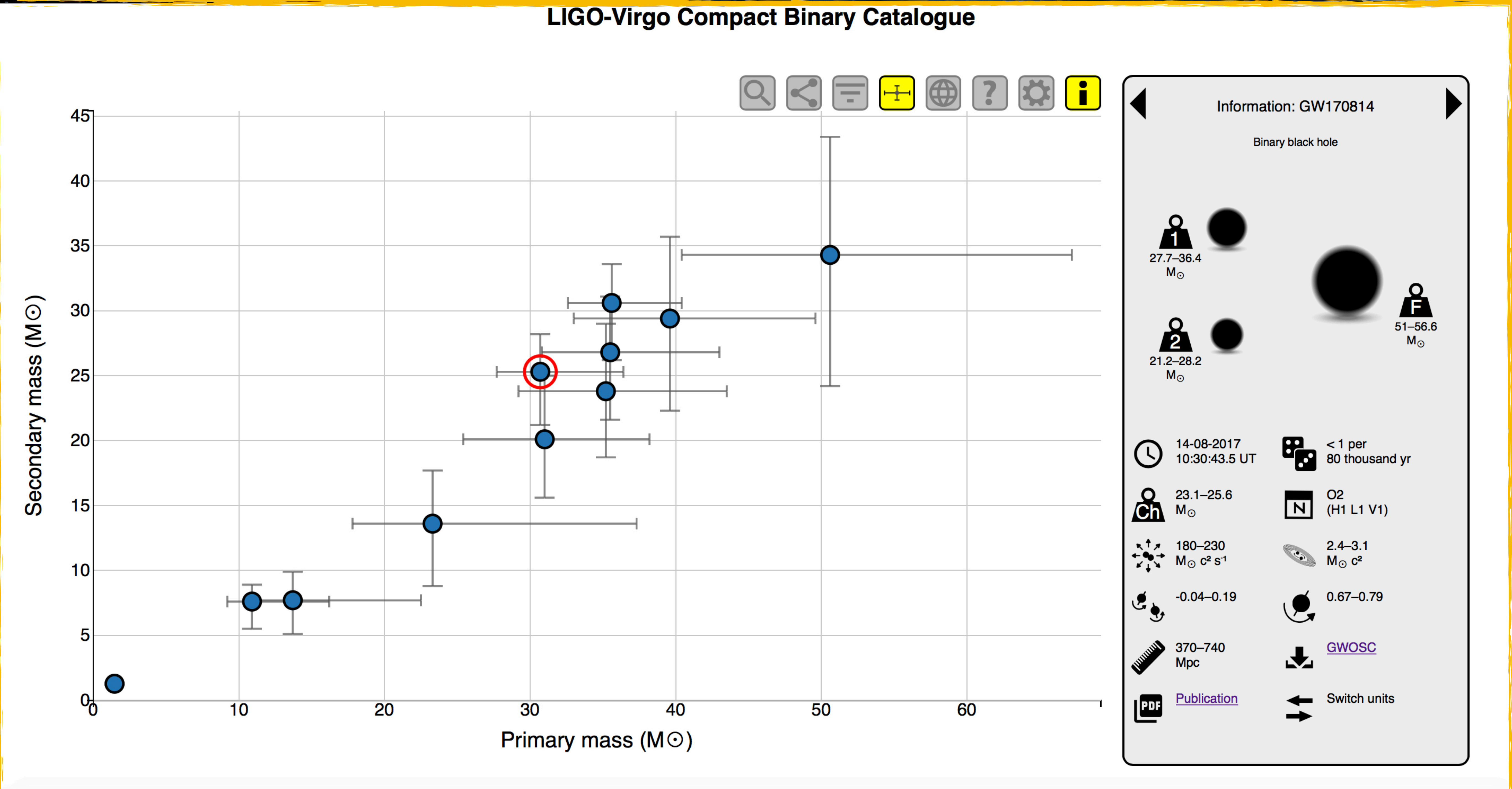
- Parameter estimation data: full posterior samples
- Skymaps
- links to: interactive plots, gracedb, associated papers / documentation
- …

> **New types of final products also outside GWOSC**

- Interactive Web Apps (see https://www.gw-openscience.org/interactive/)

Example I

http://catalog.cardiffgravity.org



Example II

https://gwsci.ciera.northwestern.edu/home/

Home Interact with Posterior Samples GW Calculations Generate Waveforms New GW Event Population Synthesis Population Generation

Welcome To Gravitational Waves Interact!

This website should allow end users to interact with gravitational wave results such as the posterior samples in an easy and intuitive way.

Name of Gravitational Wave or SuperEvent ID : TS170817b_high_spin_PhenomPNRT_posterior_samples

Param1 : m1_detector_frame_Msun

Param2 : m2_detector_frame_Msun

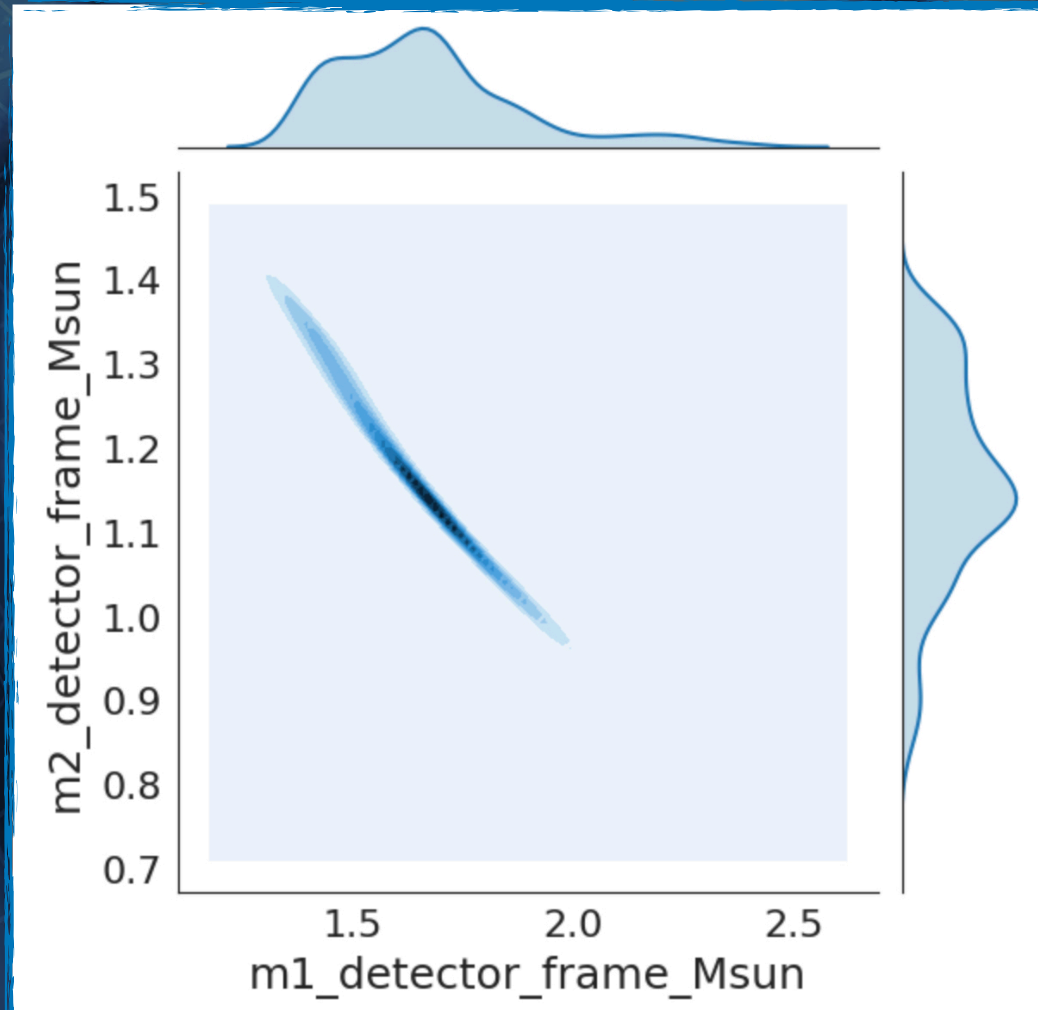
parameter 1 min : 1,3755462241

parameter 1 max : 2,7546626469

parameter 2 min : 0,7457164035

parameter 2 max : 1,375577229

Display Samples



Conclusion

- LIGO/Virgo data are already available on-line
  - ✓ Impressive results obtained by users of open data
  - ✓ Paper to describe O1 and O2 data release in preparation
- GWOSC provides also tools to analyse and understand GW data
  - ✓ Open Data Workshops have been appreciated by the students
- Resize/rethink the activity considering the growing amount of GW detected events
  - ✓ Path towards automatisation
  - ✓ Providing an API to access the database helps new possible usages of GW open data


Thank you!
Questions?

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

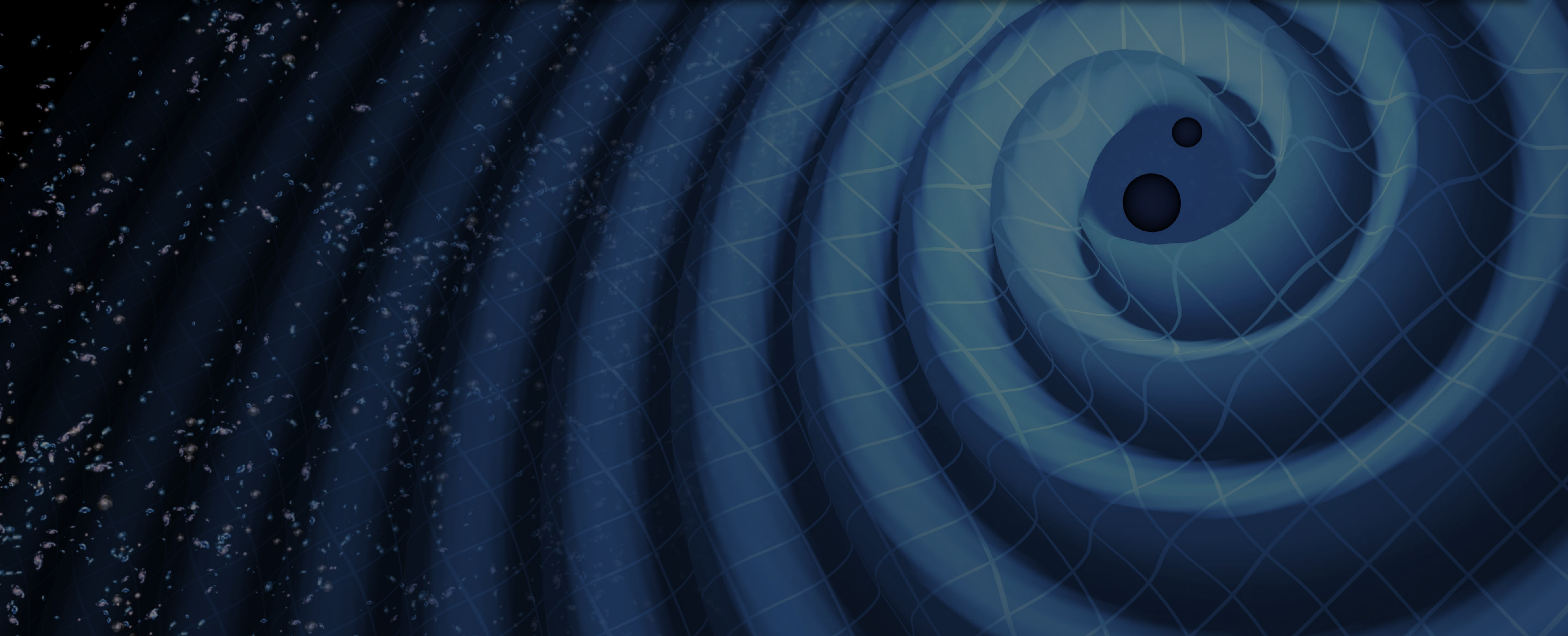
The LSC Algorithm Library Suite (LALSuite) is a collection of component packages, each of which is tagged, packaged, and released separately.

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.

Near future for GWOSC

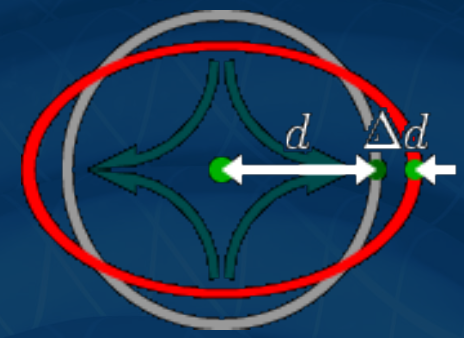
- ✓ Bulk data releases will occur every 6 months, in blocks of 6 months of data, with a latency of 18 months from the end of acquisition of each observing block. (Data Management Plan=>https://dcc.ligo.org/LIGO-M1000066/public)
    - Apr 2019-Sept 2020, Release: **Apr 2021 (first 6-month block)**
- ➢ The data around the events will be released with the catalog or with the single event publication —> in preparation



LIGO/Virgo data

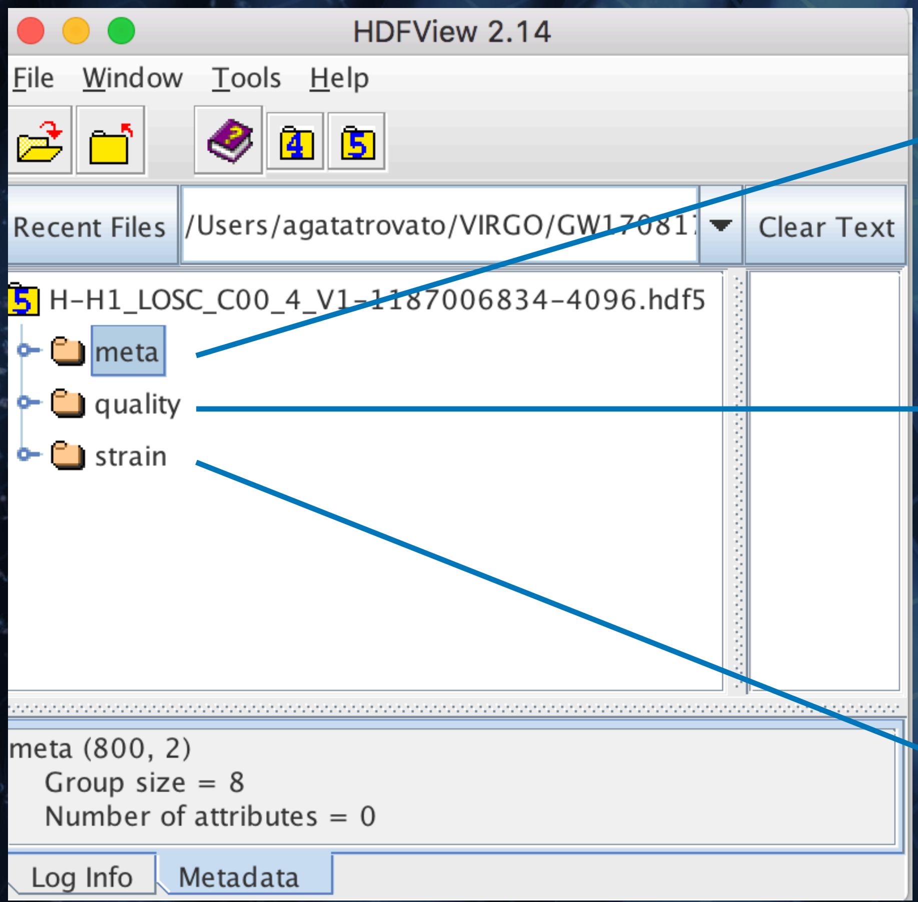
- LIGO/Virgo data: strain, data quality and hardware injections
- LIGO/Virgo data are arranged in files provided in different formats:
  - HDF5: easily readable in python, MATLAB, C/C++, and IDL
  - Frame format (.gwf)
  - Text file

Reminder: strain



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

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.