LIGO/Virgo open science

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LIGO/Virgo data

- Main information in the Ligo/Virgo data: strain
- 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



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



Reminder: gravitational wave strain h(t) -> time series



 $= \frac{change \ in \ relative \ position}{separation}$

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.

Available data sets

- Data available at www.gw-openscience.org or www.losc.ligo.org
- Two different types of data release:

Gravitational wave data surrounding discoveries

Events available at the moment:

Name	Detector	Туре	Run
GW150914	LIGO	BBH	
LVT151012	LIGO	LIGO Candidate BBH	
GW151226	LIGO BBH		01
GW170104	LIGO	BBH	O2
GW170608	LIGO	BBH	O2
GW170814	LIGO + VIRGO	BBH	O2
GW170817	LIGO + VIRGO	BNS	O2

Data taken during a whole observation run

Runs available at the moment (LIGO only):

- S5 (Nov 2005 Oct 2007)
- S6 (Jul 2009 Oct 2010)
- O1 (Sep 2015 Jan 2016)

BBH = Binary Black Hole BNS = Binary Neutron Star

Runs timeline



Where to find the data

www.gw-openscience.org/data or www.losc.ligo.org/data



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Iutorials

www.losc.ligo.org/tutorials

Tutorials

Each tutorial will lead you step-by-step through some common data analysis tasks. While LIGO data can be analyzed using libraries in many software languages (C, C++, Matlab, etc.), most of these tutorials use Python. See also the software page for more examples.

See the tutorial setup page for help installing software to run these tutorials.

Tutorials shown here are not used to produce published results. For gravitational-wave software analysis packages that are used to produce LSC and Virgo Collaboration publications, see https://losc.ligo.org/software/.

Open Data Workshop Web Course (2018) First Open Data Workshop (March 25 - 27, 2018, Caltech, Self-paced web course on LIGO data analysis Pasadena, CA): **Course Material** Lectures and hands-on introduction to working with software tools developed by the LIGO Scientific Collaboration and Virgo collaboration to access and Binary Black Hole Events process publicly available gravitational wave data. Use matched filtering to find signals hidden in noise. Project of a similar workshop in Europe (2019, after O3) Run: Azure | mybinder (Beta) View: GW150914 | LVT151012 | GW151226 | GW170104 Download: zip file with data | Jupyter notebook | python script

Tutorials about the basics of data analysis applied to the realised BBH events

Quickview Notebook

Make summary plots for any short segment of LIGO data.

Run: Azure | mybinder (Beta)

Download: IPython 4

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New releases planned: 02

- Starting with O2 the delay for public data release will shrink to 18 months (from 24 months) —> 01/09/2017 + 18 m = 01/02/2019
- BBH O2 Catalog paper under preparation
- Web version of the catalog stored on the LOSC page
 - Still to be decided: Which events? Same as the paper? Which parameters for each event?
 - Main ideas: structure of the data should be a table easy to maintain; the website should include tools for reading, plotting, interpreting the data

Name	GPS (UTC)	M (final m1, m2, chirp)	Spin	FAR	SNR	Sky localisation	Luminosity distance	
GWxxxxx								
GWyyyyyy	29							

Planned detectors sensitivity evolution



arXiv:1304.0670v4

 Multiplying the given range for the rate density for a source category, the corresponding detection rate can be calculated: <u>in O3 O(1) BBH</u> <u>events per week expected</u>
 Public alerts using GCN Notices and Circulars

$BNS = 1.4 M_{\odot} + 1.4 M_{\odot}$ $BBH = 30 M_{\odot} + 30 M_{\odot}$

	LIGO		Virgo		KAGRA	
	BNS	BBH	BNS	BBH	BNS	BBH
	range/Mpc	range/Mpc	range/Mpc	range/Mpc	range/Mpc	range/Mpc
Early	40 - 80	415-775	20 - 65	220-615	8-25	80-250
Mid	80 - 120	775-1110	65-85	615-790	25 - 40	250 - 405
Late	120 - 170	1110-1490	65-115	610-1030	40 - 140	405 - 1270
Design	190	1640	125	1130	140	1270

BBH Catalogue in Vizier

BBH catalogue should go also in Vizier!

✓ GW events have different features than the typical events stored in Vizier!

✓ POSITION:

- Can we build catalog in Vizier when sky position is poorly known?
- Can we use a probability sky map to define the event position? E.g. store for each event some central position with some large errors to indicate the event extension on the sky map?
- If yes, can this catalog be queried? For instance, give me all BBH whose sky map overlap with direction RA, δ ?
- Possibility: fits file could be produced from the MOC created by Giuseppe Greco. In the future, MOC directly as VizieR entry?
- Can this catalog be crossmatched in position with other catalogs in Vizier? Galaxies, variable stars, etc

✓ WAVEFORMS:

Can the waveforms (and eventually the templates) be stored? YES->timeseries

✓ PARAMETERS:

- Can parameters like the SNR/False alarm rate/BH masses/BH spins be stored? YES
- If yes, is it possible to search for all events with some values or (range of values) for these parameters?

✓ ADDITIONAL INFO:

✓ is it possible to add for each event a link to the main papers that discuss it? YES

Thank you for you attention!

Expected BBH rates

- The inferred rate of BBH mergers based on LIGO/Virgo observations is: 9 – 240 Gpc⁻³ yr⁻¹ [1]
- Multiplying this inferred rate for the expected range from [2], the detection rate can be calculated
- O(1) events per week expected

[1] Physical review X 6,041015 (2016)[2] arXiv:1304.0670v4

- A <u>BBH catalogue</u> is a in the plans of the collaboration already for O2.
- Contents of BBH catalogue have still to be defined. Primarily stored at losc.ligo.org

Rough estimate:

- Take this numbers only as indications of the order of magnitude
- 02:
 - 9 months long
 - LIGO BBH range ~800 Mpc
 - > O(10) BBH events detected
- 03:
 - 12 months
 - LIGO BBH range ~1300 Mpc
 - Events: 10 x (1300/800)³ x 12/9 ~
 60 BBH events expected
- 04:
 - ~2 years long
 - LIGO BBH range ~1640 Mpc
 - Events: 10 x (1640/800)³ x 2/0.75
 - ~ 230 BBH events expected