Available Data Products from LIGO-Virgo Gravitational-Wave Searches

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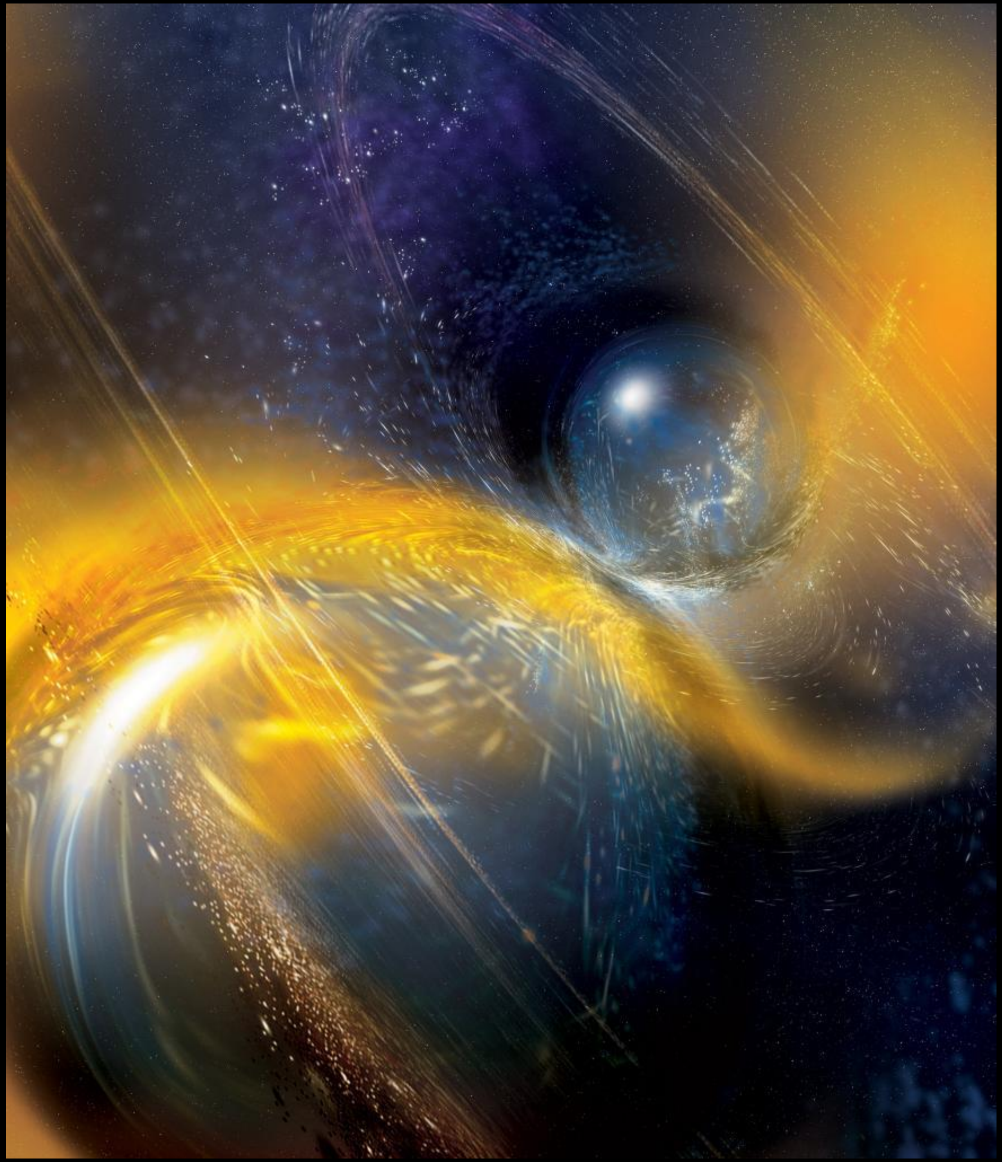
APS Mid-Atlantic Section Meeting
December 6, 2020



National Science Foundation/LIGO/Sonoma State Univ./A. Simonnet

LIGO-G2001894-v2

Detection Papers: papers.ligo.org

LIGO Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

Detection Papers

GWTC-2

- **GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run**
  arxiv.org/abs/2010.14527
- **Population Properties of Compact Objects from the Second LIGO-Virgo Gravitational-Wave Transient Catalog**
  arxiv.org/abs/2010.14533
- **Search for Gravitational Waves Associated with Gamma-Ray Bursts Detected by Fermi and Swift During the LIGO-Virgo Run O3a**
  arxiv.org/abs/2010.14550
- **Tests of General Relativity with Binary Black Holes from the second LIGO-Virgo Gravitational-Wave Transient Catalog**
  arxiv.org/abs/2010.14529
- **GWTC-2 Data Release**

GW190521

Discovery paper

- **GW190521: A Binary Black Hole Merger with a Total Mass of 150 M_o**
  Published in *Phys. Rev. Lett.* **125**, 101102 (2020)
- **GW190521 Data Release**

Gravitational Wave Open Science Center

www.gw-openscience.org

Data▾ Software▾ Online Tools▾ About GWOSC▾

GWTC-2 Data Release Documentation

Description

This data release is described in: GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run.

Strain Data

Strain data for O3a events are available through the Event Portal, reflecting events observed by Advanced LIGO and Advanced Virgo between 1 April 2019 15:00 UTC and 1 October 2019 15:00 UTC.

These events are also included in a cumulative list of all GWTC events published to date.

Click on any event, and then select a GWF, HDF, or TXT file to download strain data.

Parameter Estimation

Values for 90% confidence intervals for some parameters are displayed in the Event Portal, as described in the associated paper (See Tables IV, VI, and VIII). See parameter descriptions for additional notes. Note that parameter estimation results reported in this catalog may differ from results reported in previous publications.

Event List

Name	Version	Release	GPS ↓	Mass 1 $(M_\odot)$	Mass 2 $(M_\odot)$	Network SNR	Distance (Mpc)	χ_{eff}	Total Mass $(M_\odot)$
GW190930_133541	v1	GWTC-2	1253885759.2	$12.3^{+12.5}_{-2.3}$	$7.8^{+1.7}_{-3.3}$	9.8	780^{+370}_{-330}	$0.14^{+0.31}_{-0.15}$	$20.3^{+9.0}_{-1.5}$
GW190929_012149	v1	GWTC-2	1253755327.5	$64.7^{+22.4}_{-18.9}$	$25.7^{+14.4}_{-9.7}$	9.9	3680^{+2980}_{-1680}	$0.03^{+0.27}_{-0.27}$	$90.6^{+21.2}_{-14.1}$
GW190924_021846	v1	GWTC-2	1253326744.8	$8.8^{+7.0}_{-2.0}$	$5.0^{+1.3}_{-1.9}$	13.2	570^{+220}_{-220}	$0.03^{+0.30}_{-0.09}$	$13.9^{+5.1}_{-0.9}$
GW190915_235702	v1	GWTC-2	1252627040.7	$34.9^{+9.5}_{-6.2}$	$24.4^{+5.5}_{-6.0}$	13.1	1700^{+710}_{-640}	$0.03^{+0.19}_{-0.24}$	$59.5^{+7.5}_{-6.2}$
GW190910_112807	v1	GWTC-2	1252150105.3	$43.5^{+7.6}_{-6.2}$	$35.1^{+6.3}_{-7.0}$	13.4	1570^{+1070}_{-640}	$0.02^{+0.19}_{-0.18}$	$78.7^{+9.5}_{-9.0}$
GW190909_114149	v1	GWTC-2	1252064527.7	$43.2^{+50.7}_{-12.2}$	$27.6^{+13.0}_{-10.9}$	8.5	4770^{+3700}_{-2660}	$-0.03^{+0.44}_{-0.36}$	$71.2^{+54.3}_{-15.0}$
GW190828_065509	v1	GWTC-2	1251010527.9	$23.8^{+7.2}_{-7.0}$	$10.2^{+3.5}_{-2.1}$	11.1	1660^{+630}_{-610}	$0.08^{+0.16}_{-0.16}$	$34.1^{+5.5}_{-4.5}$
GW190828_063405	v1	GWTC-2	1251009263.8	$31.8^{+5.8}_{-3.9}$	$25.9^{+4.4}_{-4.6}$	16.0	2220^{+630}_{-950}	$0.19^{+0.15}_{-0.16}$	$57.5^{+7.5}_{-4.4}$
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}	$0.00^{+0.06}_{-0.06}$	$25.8^{+1.0}_{-0.9}$
GW190803_022701	v1	GWTC-2	1248834439.9	$36.1^{+10.2}_{-6.7}$	$26.7^{+7.1}_{-7.6}$	8.6	3690^{+2040}_{-1690}	$-0.01^{+0.25}_{-0.26}$	$62.7^{+11.8}_{-8.4}$
GW190731_140936	v1	GWTC-2	1248617394.6	$39.3^{+11.8}_{-8.2}$	$28.0^{+8.9}_{-8.4}$	8.5	3970^{+2560}_{-2070}	$0.08^{+0.24}_{-0.24}$	$67.1^{+15.3}_{-10.2}$
GW190728_064510	v1	GWTC-2	1248331528.5	$12.2^{+7.1}_{-2.2}$	$8.1^{+1.7}_{-2.6}$	13.6	890^{+250}_{-370}	$0.12^{+0.19}_{-0.07}$	$20.5^{+4.5}_{-1.3}$

Available Data (varies somewhat with the event)

GW strain data — also known as $h(t)$

Downloadable files for each published event

Bulk data releases from past observing runs

- Files downloadable from the web site
- Remote filesystem using CernVM-FS

Also available on gw-openscience.org : tutorials and recorded workshops showing ways to display and analyze strain data, etc.

Summary properties of each event

Masses, distance, spin parameters, etc.

Signal-to-noise ratios

Skymap (probabilistic localization)

- As FITS file containing HEALPix

Posterior samples from parameter estimation (PE) analyses

GWTC-2 PE for GW190814

show / hide parameters

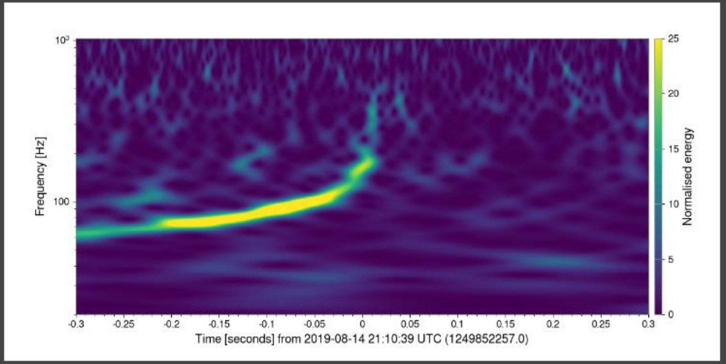
chi_eff	$0.00^{+0.06}_{-0.06}$
chirp_mass (M_sun)	$6.4^{+2.0e-02}_{-2.0e-02}$
chirp_mass_source (M_sun)	$6.1^{+6.0e-02}_{-6.0e-02}$
final_mass_source (M_sun)	$25.6^{+1.0}_{-0.9}$
luminosity_distance (Mpc)	240^{+40}_{-50}
mass_1_source (M_sun)	$23.2^{+1.1}_{-1.0}$
mass_2_source (M_sun)	$2.6^{+8.0e-02}_{-9.0e-02}$
redshift	$0.05^{+9.0e-03}_{-0.01}$
total_mass_source (M_sun)	$25.8^{+1.0}_{-0.9}$

Source File

Posterior Samples DCC Entry

Skymap

L1 strain



32sec • 16KHz:	GWF	HDF	TXT
32sec • 4KHz:	GWF	HDF	TXT
4096sec • 16KHz:	GWF	HDF	TXT
4096sec • 4KHz:	GWF	HDF	TXT

Bayesian Parameter Estimation

Repeatedly adjust the various physical parameters of the waveform model to see what fits the data from all detectors well – i.e., explore the parameter space

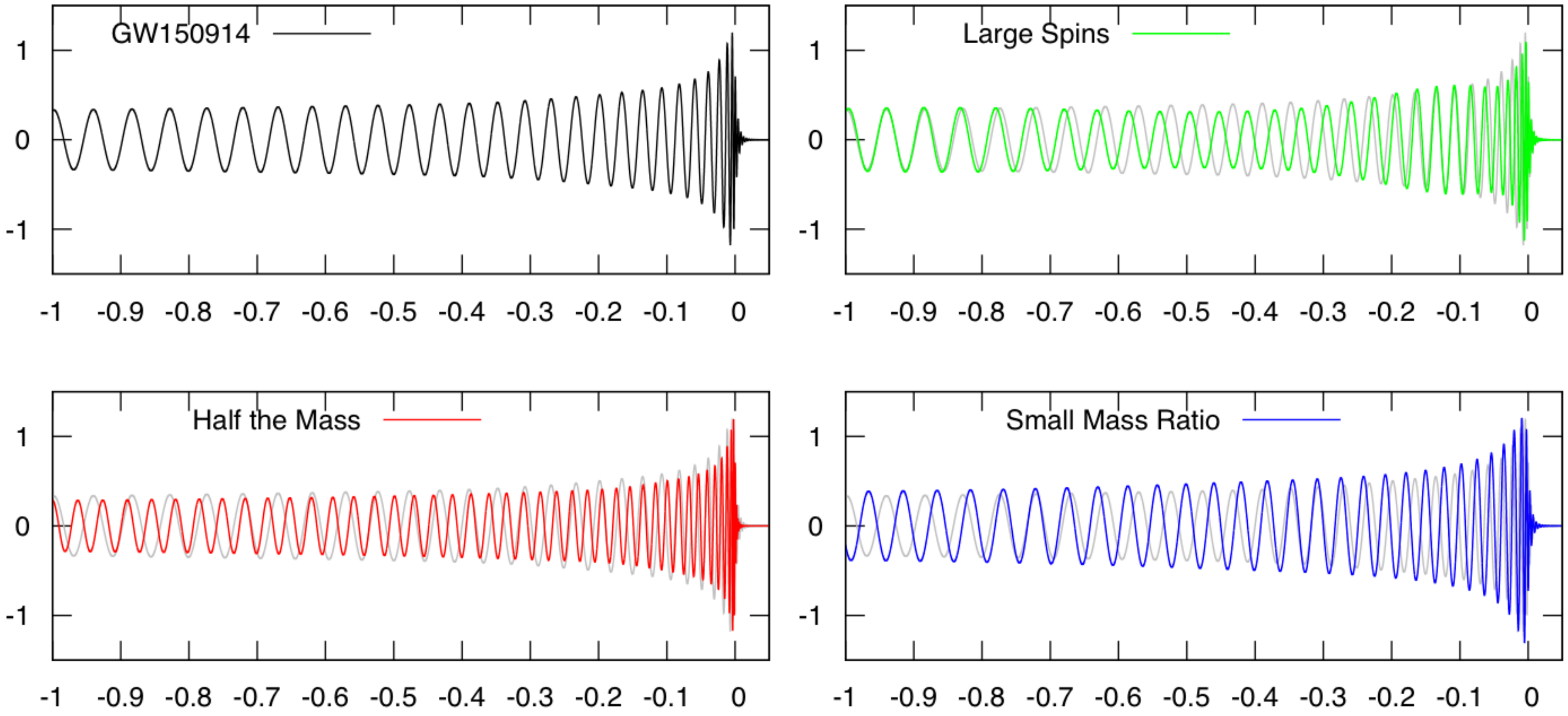


Illustration by N. Cornish and T. Littenberg

Bayesian Parameter Estimation

With a suitable algorithm for using the calculated likelihood to control “jumps” to different points in parameter space, we accumulate a collection of “samples” distributed in proportion to the Bayesian probability density in the parameter space, given the data

Each “posterior sample” is a vector of parameter values, plus calculated log-likelihood

```
from pesummary.io import read
...
data = read(file_name)
samples_dict = data.samples_dict
posterior_samples = samples_dict['PrecessingSpinIMRHM']
parameters = sorted(list(posterior_samples.keys()))
print(parameters)
```

Example code snippet adapted from
https://dcc.ligo.org/LIGO-P2000223/public

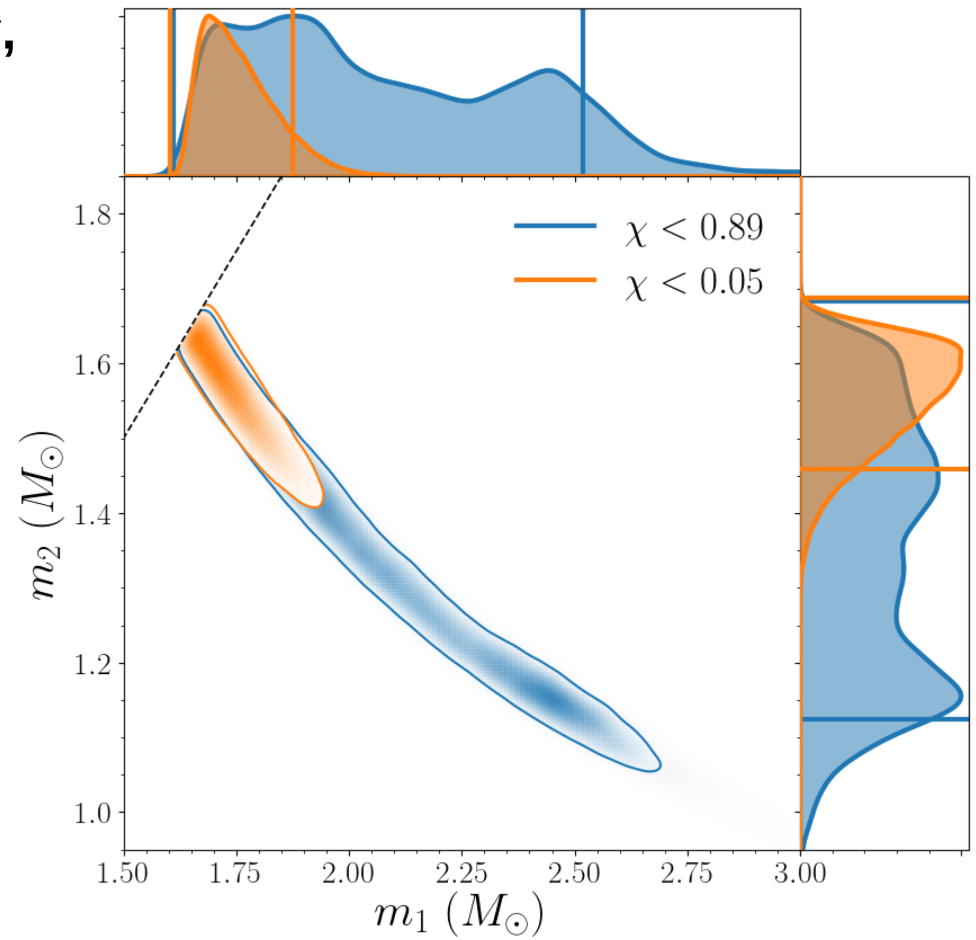
```
['Npts', 'a_1', 'a_2', 'chi_eff', 'chi_p', 'chirp_mass', 'chirp_mass_source', 'comoving_distance', 'cos_iota', 'cos_theta_jn',
'cos_tilt_1', 'cos_tilt_2', 'dec', 'final_mass', 'final_mass_non_evolved', 'final_mass_source',
'final_mass_source_non_evolved', 'final_spin', 'final_spin_non_evolved', 'geocent_time', 'inverted_mass_ratio', 'iota',
'log_likelihood', 'luminosity_distance', 'mass_1', 'mass_1_source', 'mass_2', 'mass_2_source', 'mass_ratio', 'neff', 'p',
'peak_luminosity', 'peak_luminosity_non_evolved', 'phase', 'phi_1', 'phi_12', 'phi_2', 'phi_jl', 'ps', 'psi', 'psiJ', 'ra',
'radiated_energy', 'radiated_energy_non_evolved', 'redshift', 'spin_1x', 'spin_1y', 'spin_1z', 'spin_2x', 'spin_2y',
'spin_2z', 'symmetric_mass_ratio', 'theta_jn', 'tilt_1', 'tilt_2', 'total_mass', 'total_mass_source']
```

Why Posterior Samples Can Be Useful

The parameters are all varied simultaneously, so you can investigate correlations and conditional distributions, as well as apply different priors

Example from GW190425:

m_1 versus m_2 with different priors on the neutron star spins

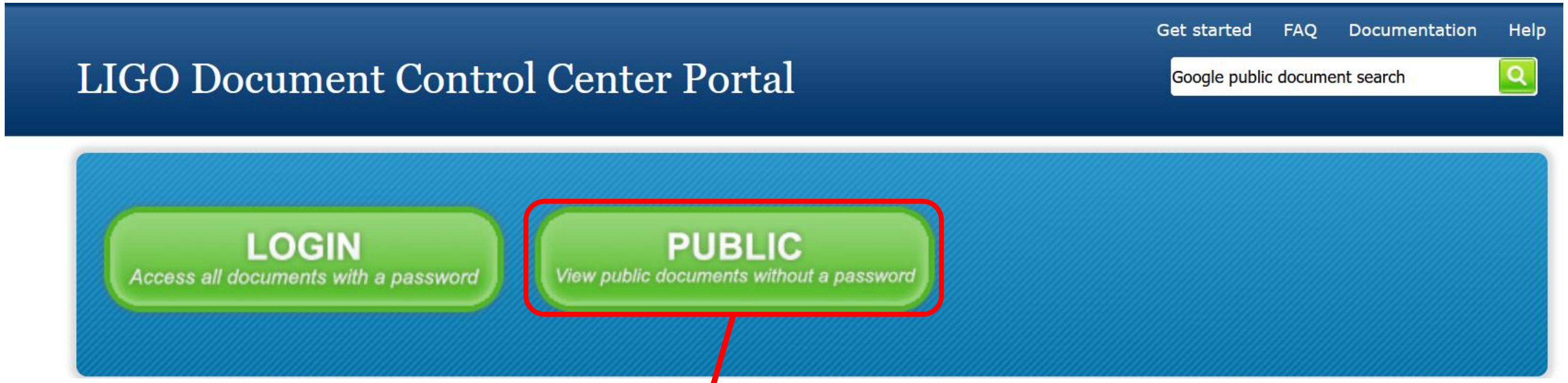


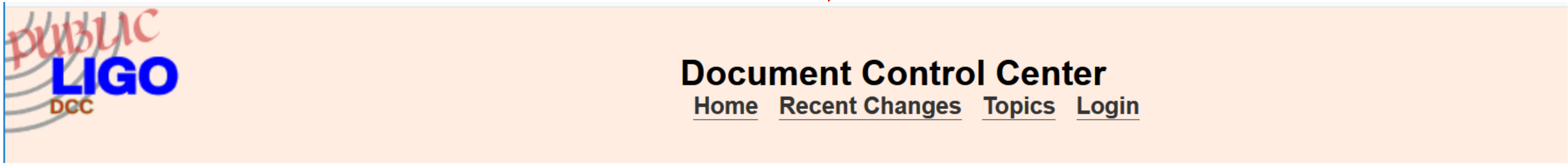
Abbott et al., ApJL 892, L3
https://arxiv.org/abs/2001.01761

But wait, there’s more!

Besides the event-focused data products in the GW Open Science Center, we generally provide other data products specific to each published paper in the LIGO Document Control Center (DCC)

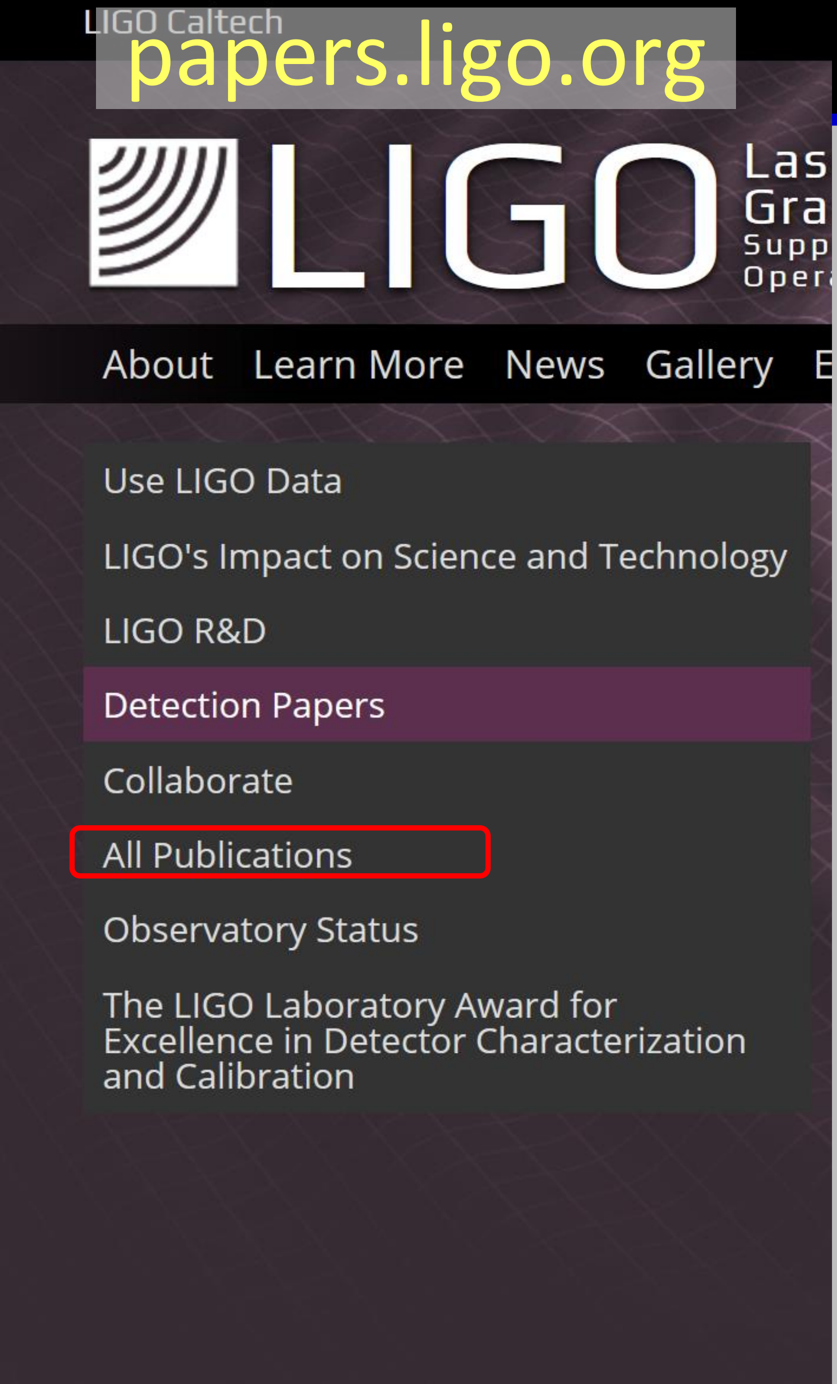
dcc.ligo.org



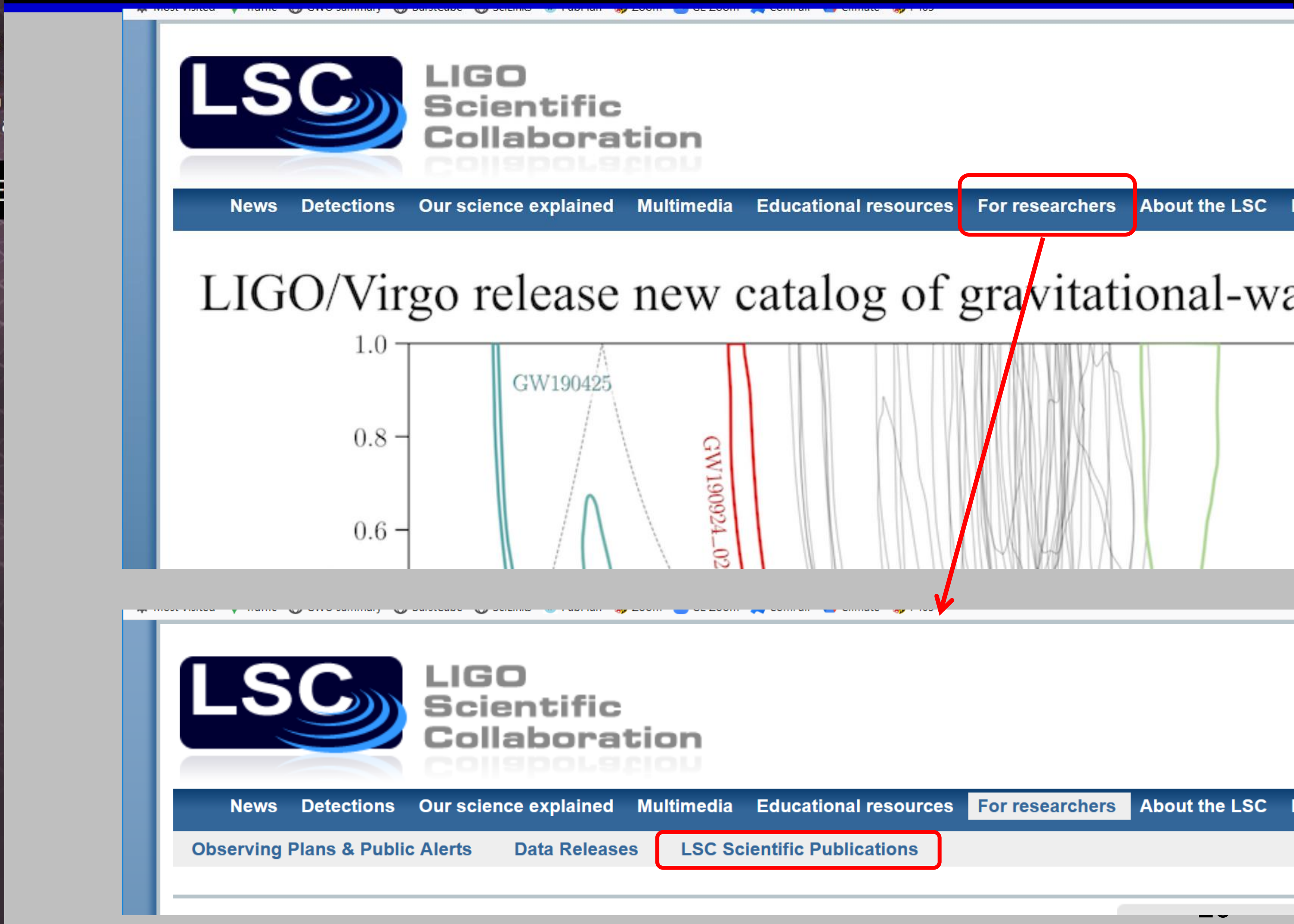


However, the best way to find all the LIGO-Virgo result papers is via either papers.ligo.org or www.ligo.org

papers.ligo.org



www.ligo.org



Publications of the LIGO Scientific Collaboration and Virgo Collaboration

Note: since 2010, most LSC papers are co-authored with the Virgo Collaboration.

Highlighting: Event discoveries Multi-messenger

Click to toggle doi information BibTeX file for published papers

The DCC records generally include paper-specific data products

Release Date	Title	Keywords	Science Summary	Journal citation	arXiv Preprint	Public DCC
Oct 28, 2020 *Recent*	**GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run**	O3 CBC	summary	*Submitted to PRX*	2010.14527	P2000061
Oct 28, 2020 *Recent*	**Tests of general relativity with binary black holes from the second LIGO-Virgo gravitational-wave transient catalog**	O3 CBC	summary	*Submitted to PRD*	2010.14529	P2000091
Oct 28, 2020 *Recent*	**Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog**	O3 CBC	summary	*Submitted to ApJL*	2010.14533	P2000077
Oct 28, 2020 *Recent*	**Search for Gravitational Waves Associated with Gamma-Ray Bursts Detected by Fermi and Swift during the LIGO-Virgo Run O3a**	O3 GRB	summary	*Submitted to ApJ*	2010.14550	P2000040
Sep 2, 2020	**GW190521: A Binary Black Hole Merger with a Total Mass of 150 Msun**	O3 GW190521	summary	Phys. Rev. Lett. **125**, 101102 (2020)	2009.01075	P2000020
Sep 2, 2020	**Properties and astrophysical implications of the 150 Msun binary black hole merger GW190521**	O3 GW190521	summary	Astrophys. J. Lett. **900**, L13 (2020)	2009.01190	P2000021
Jul 28, 2020	**Gravitational-wave constraints on the equatorial ellipticity of millisecond pulsars** (*by LSC, Virgo, and radio astronomers*)	O3 CW	summary	Astrophys. J. Lett. **902**, L21 (2020)	2007.14251	P2000029
Jun 23, 2020	**GW190814: Gravitational Waves from the Coalescence of a 23 Solar Mass Black Hole with a 2.6 Solar Mass Compact Object**	O3 GW190814	summary	Astrophys. J. Lett. **896**, L44 (2020)	2006.12611	P190814
Apr 17, 2020	**GW190412: Observation of a Binary-Black-Hole Coalescence with Asymmetric Masses**	O3 GW190412	summary	Phys. Rev. D **102**, 043015 (2020)	2004.08342	P190412
Feb 26, 2020	**Trigger Data to Accompany "GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs"**	O1 O2 CBC	-	-	-	P1900392
Jan 6, 2020	**GW190425: Observation of a compact binary coalescence with total mass ~3.4 Msun**	O3 GW190425	summary	Astrophys. J. Lett. **892**, L3 (2020)	2001.01761	P190425

Example 1

Sometimes, the “data behind the figures and tables” is attached as additional files

PUBLIC LIGO DCC

LIGO Document P2000029-v7

Home Recent Changes Topics Login

Gravitational-wave constraints on the equatorial ellipticity of millisecond pulsars

Document #:
LIGO-P2000029-v7
Document type:
P - Publications

Login to modify

Abstract:
We present a search for continuous gravitational waves from five radio pulsars, comprising three recycled pulsars (PSR J0437-4715, PSR J0711-6830, and PSR J0737-3039A) and two young pulsars: the Crab pulsar (J0534+2200) and the Vela pulsar (J0835-4510). We use data from the third observing run of Advanced LIGO and Virgo combined with data from their first and second observing runs. For the first time we are able to match (for PSR J0437-4715) or surpass (for PSR J0711-6830) the indirect limits on gravitational-wave emission from recycled pulsars inferred from their observed spin-downs, constrain their equatorial ellipticities to be less than 10^-8. For each of the five pulsars, we perform targeted searches that assume a tight coupling between the gravitational-wave and electromagnetic signal phase evolution. We also present constraints on PSR J0711-6830, the Crab pulsar and the Vela pulsar from a search that relaxes this assumption, allowing the gravitational-wave signal to vary from the electromagnetic expectation within a narrow band of frequencies and frequency derivatives.

Other Versions:
LIGO-P2000029-v6
28 Jul 2020, 09:16

Files in Document:

- paper (GWPulsarSearchPaper-9.pdf, 1.5 MB)

Other Files:

- ApJ style MRT version of the Table 3 results (resultstable.txt, 7.1 kB)
- Fig 1 (Fig1_PSD.zip, 727.9 kB)
- Fig 2 (Figure2.zip, 421.5 kB)
- Fig 3 (Figure3.zip, 466.5 kB)
- Fig 4 (Fig4_detection_statistic.zip, 89.2 kB)
- Fig 5 (Fig5_PSD_vela.zip, 241.6 kB)
- Fig 6 (Fig6_NB_ul.zip, 49.8 kB)

Example 2

Other times, there is a separate, related DCC entry containing data products

Public LIGO DCC

LIGO Document P2000077-v11

Home Recent Changes Topics Login

Population properties of compact objects from the second LIGO–Virgo Gravitational-Wave Transient Catalog

Document #:
LIGO-P2000077-v11
Document type:
P - Publications

Login to modify

Other Versions:

Abstract:

We report on the population properties of the 47 compact binary mergers detected with a false-alarm rate (FAR) < $1\,\mathrm{yr}^{-1}$ in GWTC-2, including all Advanced LIGO–Virgo observing runs through the most recent observing run O3a. We investigate the mass distribution, spin distribution, and merger rate as a function of redshift. We observe several binary black hole (BBH) population characteristics not discernible until now. First, we find that the primary mass spectrum contains structure beyond a power-law distribution with a sharp high-mass cut-off; it is more consistent with a broken power law with a break at $39.7^{+20.3}_{-9.1}\,M_\odot$, or a power law with a Gaussian feature peaking at $33.5^{+4.5}_{-5.5}\,M_\odot$ (90% credible interval). While the primary mass distribution must extend to $\sim 65\,M_\odot$ or beyond, only $2.9^{+3.4}_{-1.7}\%$ of systems have primary masses greater than $45\,M_\odot$. At low masses, we find that the primary mass spectrum has a global maximum at $7.8^{+2.2}_{-2.1}\,M_\odot$, consistent with a gap between $\sim 2.6\,M_\odot$ and $\sim 6\,M_\odot$. Second, we find evidence that a nonzero fraction of BBH systems have component spins misaligned with the orbital angular momentum, giving rise to precession of the orbital plane. Moreover, we infer that 12% to 44% of BBH systems have spins tilted by more than 90° with respect to their orbital angular momentum, giving rise to a negative effective inspiral spin parameter. Third, we provide improved estimates for merger rates using astrophysically motivated mass distributions: for BBH, $R_{\mathrm{BBH}} = 23.9^{+14.9}_{-8.6}\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$ and for binary neutron stars (BNS), $R_{\mathrm{BNS}} = 320^{+490}_{-240}\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$. We constrain the BBH merger rate as a function of redshift and find that the rate likely increases with redshift (85% credibility), but not faster than the star-formation rate (87% credibility). Additionally, we examine recent exceptional events in the context of our population models, finding that the asymmetric masses of GW190412 and the high component masses of GW190521 are consistent with our population models, but the low secondary mass of GW190814 makes it an outlier. We discuss the implications of these results for compact binary formation and for the evolution of massive stars.

MathJax: Disable

Files in Document:

- main.pdf (3.6 MB)

Topics:
- Compact Binaries

Authors:
- LIGO Scientific Collaboration
- Virgo Collaboration

Author Groups:

- LVC

Related Documents:
- LIGO-P2000434: Data Release for "Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog"

Referenced by:
- LIGO-P2000434-v1: Data Release for "Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog"
- LIGO-P2000061-v10: GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo During the First Half of the Third Observing Run

Acknowledgements

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