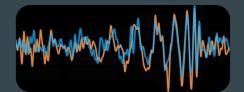


# Status of the O4 run

 $\bullet \bullet \bullet$ 

and LIGO-Virgo-KAGRA searches





David Keitel (Universitat de les Illes Balears)

for the LIGO Scientific Collaboration, Virgo Collaboration and KAGRA Collaboration UIB

CGWNS workshop 2024, Hannover (Germany), 2024-06-17



LIGO-G2400497-v3

## The LVK detector network and collaboration



- >2000 scientists from >200 groups on 5 continents
- 52 papers from O3
- 1 from O4 so far



2002127-v25

2015



100-140

Mpc

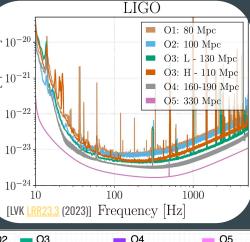
40-50

Mpc

07

Mpc





150 -160+

Mpc

40-80

Mpc

Mpc

1 - 3

Mpc

240-325

Mpc

See text

25-128

Mpc

				-	- 3							
01 2015 - 2016			<b>02</b> 2015 2017		2007	de la	and a	-			03a+b 2019 - 2020	
36 3)	23 H	14 7.7	31 20	п 76	50 34	35 24	31 25	15 13	35 27	40 29	88 22	25 18
63		21	49	18	80	56	53	5 <b>2.8</b>	60	65	105	41
силози		CW15/228	сwrmana	сууловов	cwrotes	султовоя	смитова	cwrnourr	сwr706f8	cwr98823	CW190401,00009	GW190408_818002
30 8.3	35 24	48 32	41 32	2 14	107 77	43 28	23 13	36 18	39 28	37 25	66 41	95 69
<b>37</b>	56	76	70	3.2	175	69	35	52	65	59	101	156
GW190412	GW1904I3_052954	GW190413,134308	GW190421,213856	CWY90L05	CW/30425_190642	CW790003,285404	cwrso532_380714	CW190513, 205428	сw1905на, окана	cwrsosr.osson	CW190593_153544	GW190531
42 33	37 23	69 48	57 36	35 24	54 41	67 38	12 8.4	18 13	37 21	13 7.8	12 6.4	38 29
71	56	111	87	56	90	99	19	30	55	20	<b>17</b>	64
CWY90521_074389	cwmes27.encoss	CW190462_775627	CW190620, 030421	cwrsosiol assass	GW190705_203306	CW190706_222641	CW190707.085536	GW1907608_2320457	CW190779,25594	силяотар. соовае	CW/990728_794728	сминотии оневая
12 8.1	42 29	37 27	48 32	23 2.6	32 26	24 10	44 36	35 24	44 24	9.3 2)	89 5	21 16
20	67	62	76	26	55	33	76	57	66	11	13	35
cwraerrae.ossano	CW19073L140936	Cwr90803.022701	cwr90066_21107	CWM0084	CW190608L063405	GW190828.065509	GW180990_303607	cwr9096,235702	CW1909NE_200658	CW190917,114630	cw190824.621846	CW790025,222845
40 23	BI 24	12 7.8	12 7.9	11 7.7	65 47	29 59	12 8.3	53 24	11 6.7	27 19	12 8.2	25 18
61	102	19	19	18	107	34	20	76	17	45	19	41
CW190508, 050336	CW/90929_00249	CW790800,133541	GW191103.012549	cwranos, 143521	GW19809.00777	CWYNIIIL OTTYSI	CW198056_115259	cwr91027.056227	GW191129_134029	cvv99204_190529	cwwsigos.cmccs	cw14055.223052
12 77	31 12	45 35	49 37	9 1.9	36 28	59 14	42 33	34 29	10 7.3	38 27	51 12	36 27
19	32	76	82	11	61	7.2	71	60	17	63	61	60
силясяе 213338	GW1910195,16320	CWM90222 0336377	GW196230, 180458	CW20005, 162426	GW200712 X56636	GW200115_042309	GW200008.02200	GW200128.045458	CW200202.354383	CW/2002004.130007	CW2000000 2220677	5W2002091.085462
24 2.8	51 30	38 28	87 6	39 28	40 33	19 14	38 20	28 15	36 14	34 28	13 7.8	34 14
27	78	62	141	64	69	32	56	42	47	59	20	53
CW200200.092254	CW/200216-220804	CW200239_094495	GW200220_068028	CW/200220_104660	GW200224, 222234	GW200225, 060421	Gw200302_01988	GW200306_093774	GW/200306.773609	GW200311_116663	CW200036_299796	GW200322.097833

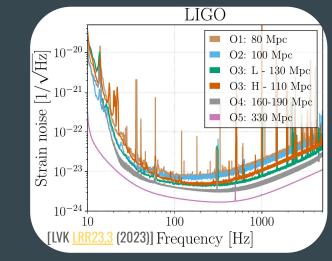






#### LVK instrumental science

- Achieving our extreme strain sensitivities requires cutting-edge technology in vacuum systems, mirror materials, suspensions, lasers, quantum optics, ...
- Crucial contributions to running and exploiting the detectors: commissioning, calibration, data characterization, mitigating noise artifacts, open data preparation, ...
   GOING INTO 04 – WHA GOING INTO
- Exciting challenges ahead for further improving the LVK network and for future detectors!

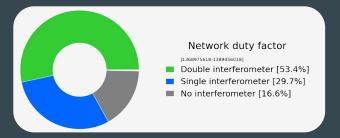


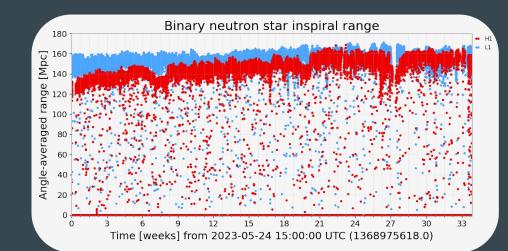


### The O4 run so far

gwosc.org/detector\_status/

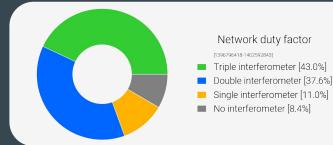
- 04a: 2023/05/27 2024/01/16 (LIGO)
  - $\circ$  duty cycles 67.5% (Hanford), 69% (Livingston)

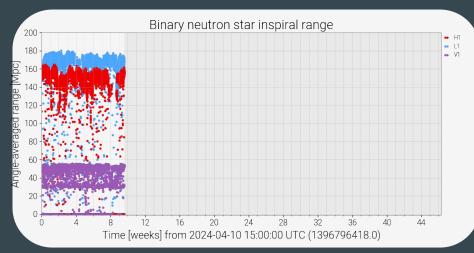




 O4b: 2024/04/03 – 2025/06/09 (LIGO+Virgo, KAGRA to join later)

 duty cycles so far: 61% (H), 75% (L), 79% (V)





### The O4 run so far

public alerts: <u>gracedb.ligo.org</u> | <u>emfollow.docs.ligo.org/userguide</u>
 | <u>chirp.research.exeter.ac.uk</u> (also mobile apps)

O4 Significant Detection Candidates: 107 (121 Total - 14 Retracted)

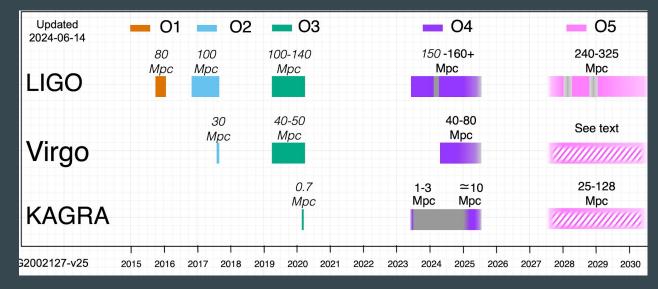
O4 Low Significance Detection Candidates: 2012 (Total) [2024/06/16]

- now also including marginal candidates (to enable deep EM coincidence searches) and BNS pre-merger alerts
- one first event published in detail: GW230529\_181500  $\rightarrow \frac{arxiv.org/abs/2404.04248}{(details in a moment)}$
- no promising low-latency electromagnetic counterparts yet
- full CBC results to be reported in two catalog updates (O4a, full O4)
- continued searches for bursts, C(G)Ws, stochastic backgrounds, dark matter, ...

GraceDB

#### 04 extension and 05 schedule

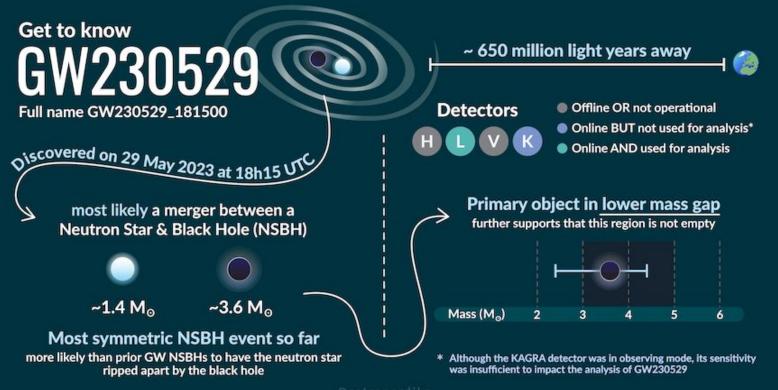
**new schedule**  $\rightarrow$  *(as of this weekend)* 



#### observing.docs.ligo.org/plan/:

"LIGO, Virgo, and KAGRA have adopted a change to the end date for the O4 observing run, which previously had been set as February 2025. It has been decided to extend the O4 run, to allow for greater preparation of upgrade hardware that will be installed for O5. The new end date for O4 is 9 June 2025."

#### GW230529 [Abac+ (LVK) <u>arXiv:2404.04248</u>]

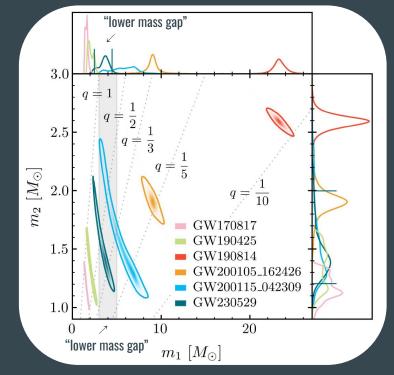


@astronerdika

#### GW230529 [arXiv:2404.04248]

- online L1-only detection with GstLAL, MBTA, PyCBC (SNRs 11.3–11.6, IFAR > 60 yr)
- no confirmed EM counterpart, no clear tidal constraints

Primary mass $m_1/M_{\odot}$	$3.6^{+0.8}_{-1.2}$
Secondary mass $m_2/M_{\odot}$	$1.4\substack{+0.6 \\ -0.2}$
Mass ratio $q = m_2/m_1$	$0.39\substack{+0.41 \\ -0.12}$
Total mass $M/M_{\odot}$	$5.1^{+0.6}_{-0.6}$
Chirp mass $\mathcal{M}/M_{\odot}$	$1.94\substack{+0.04 \\ -0.04}$
Detector-frame chirp mass $(1+z)\mathcal{M}/M_{\odot}$	$2.026\substack{+0.002\\-0.002}$
Primary spin magnitude $\chi_1$	$0.44\substack{+0.40 \\ -0.37}$
Effective inspiral-spin parameter $\chi_{\rm eff}$	$-0.10\substack{+0.12\\-0.17}$
Effective precessing-spin parameter $\chi_{\rm p}$	$0.40\substack{+0.39\\-0.30}$
Luminosity distance $D_{\rm L}/{\rm Mpc}$	$201^{+102}_{-96}$
Source redshift $z$	$0.04^{+0.02}_{-0.02}$

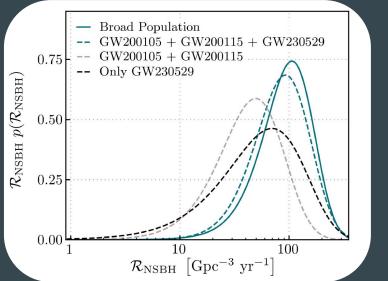


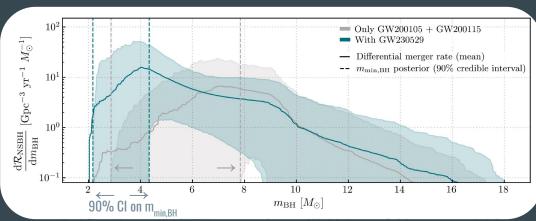
#### GW230529 [arXiv:2404.04248]

Nature of the components, marginalised over different equations of state with "NS" defined via the maximum mass allowed by each.

	$\chi_1, \chi_2 \le 0.99$	$\chi_1, \chi_2 \le 0.05$	Power law + Dip + Break
$P(m_1 \text{ is NS})$	$(2.9\pm0.4)\%$	< 0.1%	$(8.8\pm2.8)\%$
$P(m_2 \text{ is NS})$	$(96.1 \pm 0.4)\%$	> 99.9%	$(98.4 \pm 1.3)\%$

#### Interesting questions on *how* the mass gap is filled...

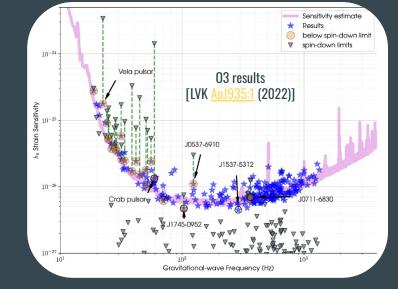


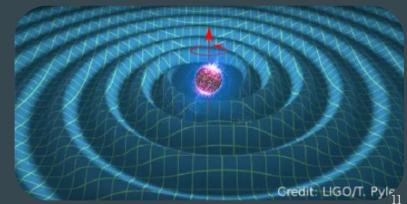


### C(G)W 04 plans

- Known pulsars:
  - targeted (single-template) searches at  $f = f_{rot}$  and  $f = 2f_{rot}$
  - narrowband searches arround  $f=2f_{rot}$
  - $\circ$  r-mode searches
  - post-glitch long-transient searches
- Directed searches (known sky location, unknown frequency):
  - isolated NSs in galactic supernova remnants
  - isolated NSs in galactic centre and globular clusters
  - Scorpius X-1, other low-mass X-ray binaries, and accreting millisecond X-ray pulsars
  - binary neutron star post-merger remnants

#### LVK OBS white paper 2024: <u>LIGO-T2300406</u>

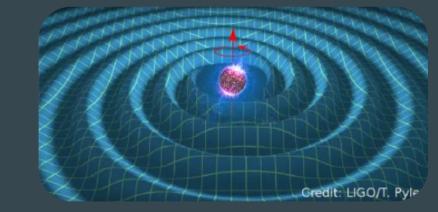


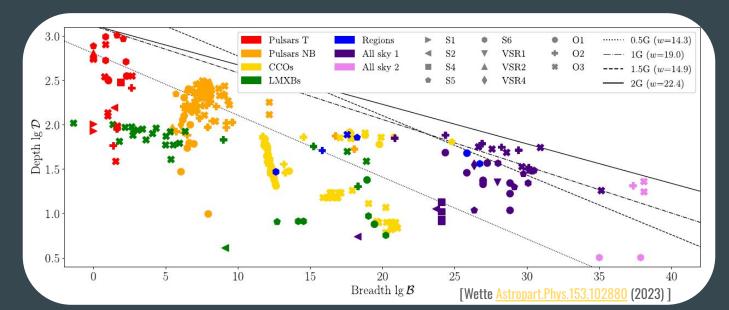


### C(G)W O4 plans

- All-sky searches:
  - unknown isolated NSs
  - $\circ$  unknown generic CW sources
  - $\circ$  unknown NSs in binaries

#### LVK OBS white paper 2024: LIGO-T2300406

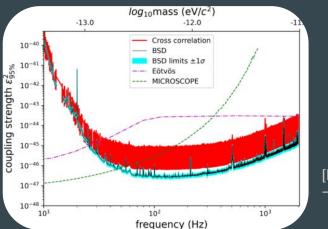




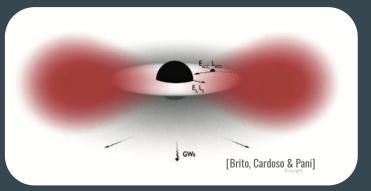
### C(G)W O4 plans: new physics

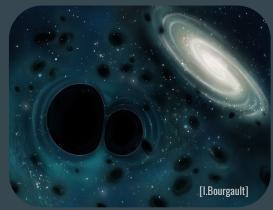
#### LVK OBS white paper 2024: LIGO-T2300406

- search for modified gravity effects in targeted searches
- primordial black holes as dark matter candidates (all-sky searches for CW-like early inspiral of low-mass binaries)
- indirect detection of particle dark matter: GW emission from ultralight bosons (axion) clouds around spinning BHs (directed & all-sky searches)
- DM direct detection via interaction with the GW detectors "no-sky" modulation searches



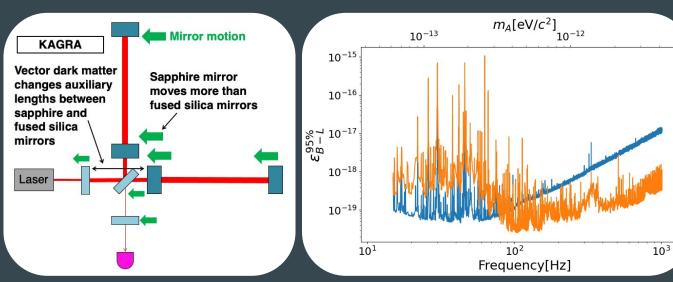
[LVK <u>PRD105.063030</u> (2022) – plot updated in recent <u>erratum]</u>

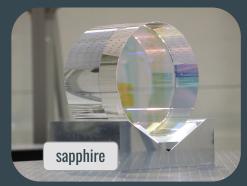


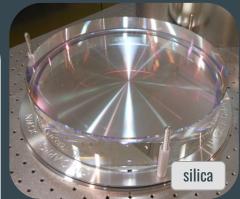


### Latest O3 C(G)W result: KAGRA dark matter search

- Abac+ (LVK) <u>arXiv:2403.03004</u>
- KAGRA particularly promising for vector dark matter coupled to the "B-L channel", due to different coupling to different mirror materials:
  - sapphire (main test masses)
  - fused silica (auxiliary mirrors)

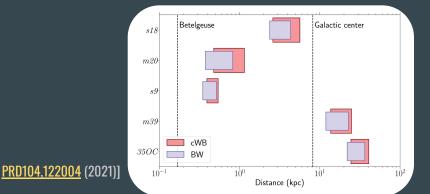


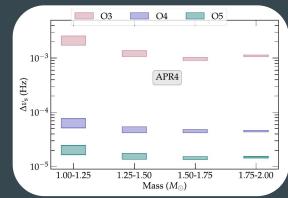


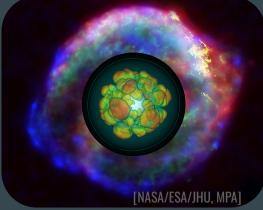


#### Other GWs from NSs: bursts

- CBCs (BBH, BNS, NSBH) & C(G)Ws: well-modelled signals, matched filter searches
- Other GW transients: core-collapse supernovae, magnetars, accretion disk instabilities, highly eccentric BBHs, cosmic strings, ...
   → search with more generic methods (excess power, pattern recognition, ...)
- Non-detections can still yield interesting physical constraints, e.g. on nearby supernovae, glitching pulsars, ...







[Lopez+ PRD106.103037 (2022)]

### GW open data & software

#### • <u>gwosc.org</u>

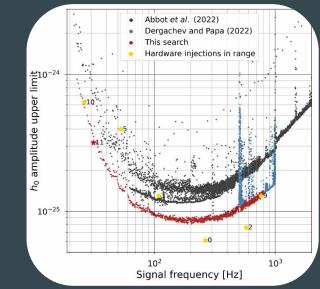
- full strain data of observing runs 01–02 [<u>SoftwareX 13,100658 (2021)</u>] and 03 [<u>ApJS267:29 (2023)</u>]
- posterior samples for all significant events (first O4 release: <u>GW230529</u>)
- Future data release plans: <u>LIGO-M1000066</u>
- Commitment to open-source software:
  - o <u>LIGO-M1500244</u>
  - o <u>git.ligo.org/explore</u>
  - o <u>computing.docs.ligo.org/guide/software/</u>

#### Gravitational Wave Open Science Center

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

Explore Data

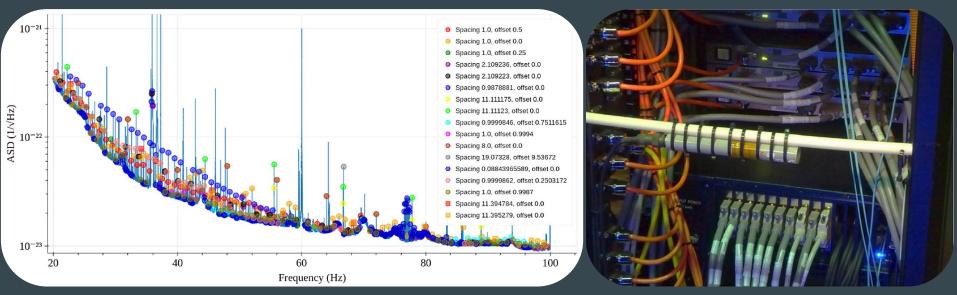




example Einstein@Home usage [Steltner+ <u>ApJ952:55</u> (2023)]

### C(G)Ws – data quality challenges

- Reminder: crucial contributions to running and exploiting the detectors: commissioning, calibration, data characterization, mitigating noise artifacts, ...
- Especially for C(G)Ws, as in every observing run, *line hunting* efforts are ongoing.
- Lines lists and "good segments" will be published via GWOSC/DCC as usual.



[Covas+ <u>PRD97,082002</u> (2018)] – 01 era, tools and procedures significantly improved since

#### **Final words**

• Through decades of work of a global community, "GW astrophysics" became reality.



- Rich science returns from compact binary detections: unprecedented insights into the physics, populations and evolutionary history of compact objects in our universe.
- Many other science targets are within reach, including C(G)Ws from neutron stars or more exotic physics.
- 04 providing the best sensitivity and longest run duration yet.
- The global detector network continues to improve and grow; future detectors will push cosmic frontiers.

#### Acknowledgments

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