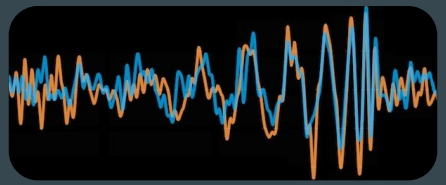
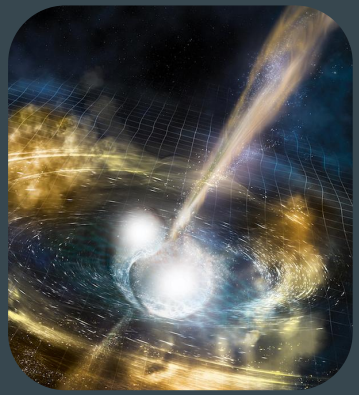
Status of the O4 run

...

and LIGO–Virgo–KAGRA searches





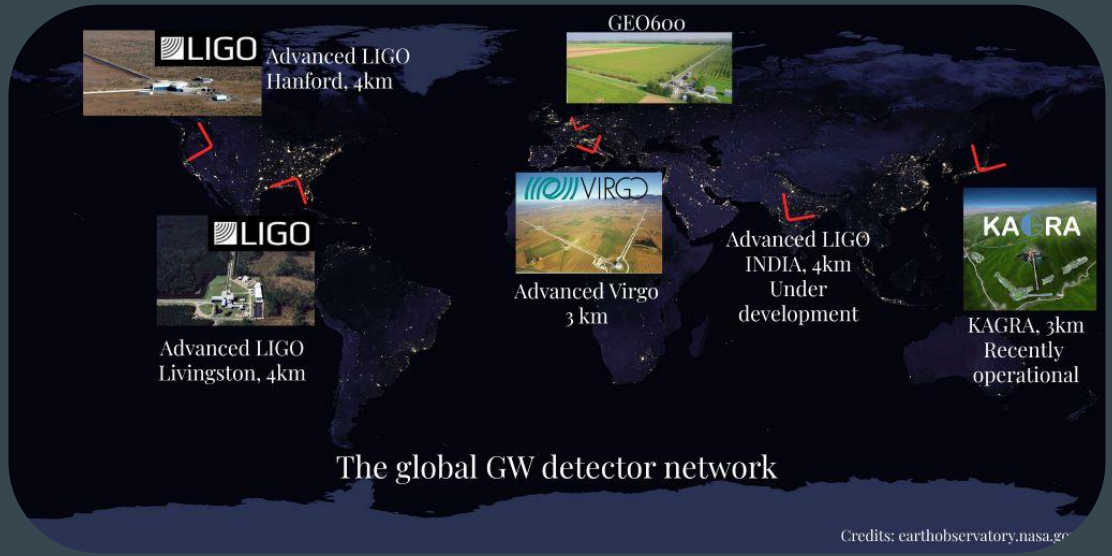
David Keitel (Universitat de les Illes Balears)

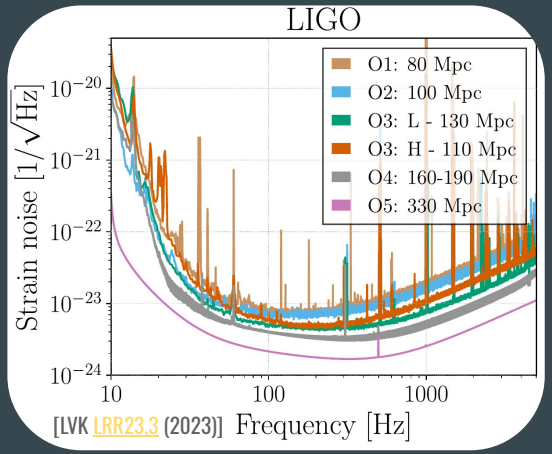
for the LIGO Scientific Collaboration,
Virgo Collaboration and KAGRA Collaboration

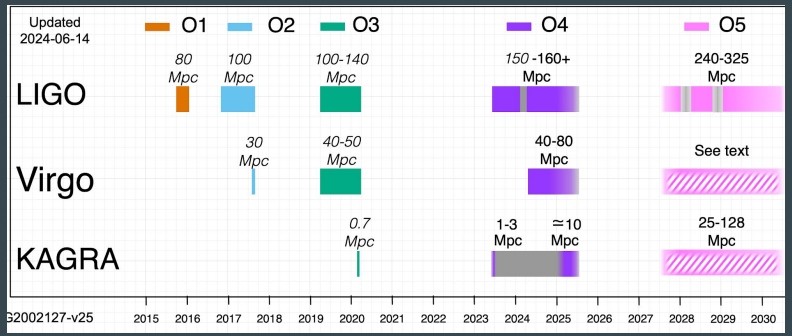
CGWNS workshop 2024, Hannover (Germany), 2024-06-17

LIGO-G2400497-v3

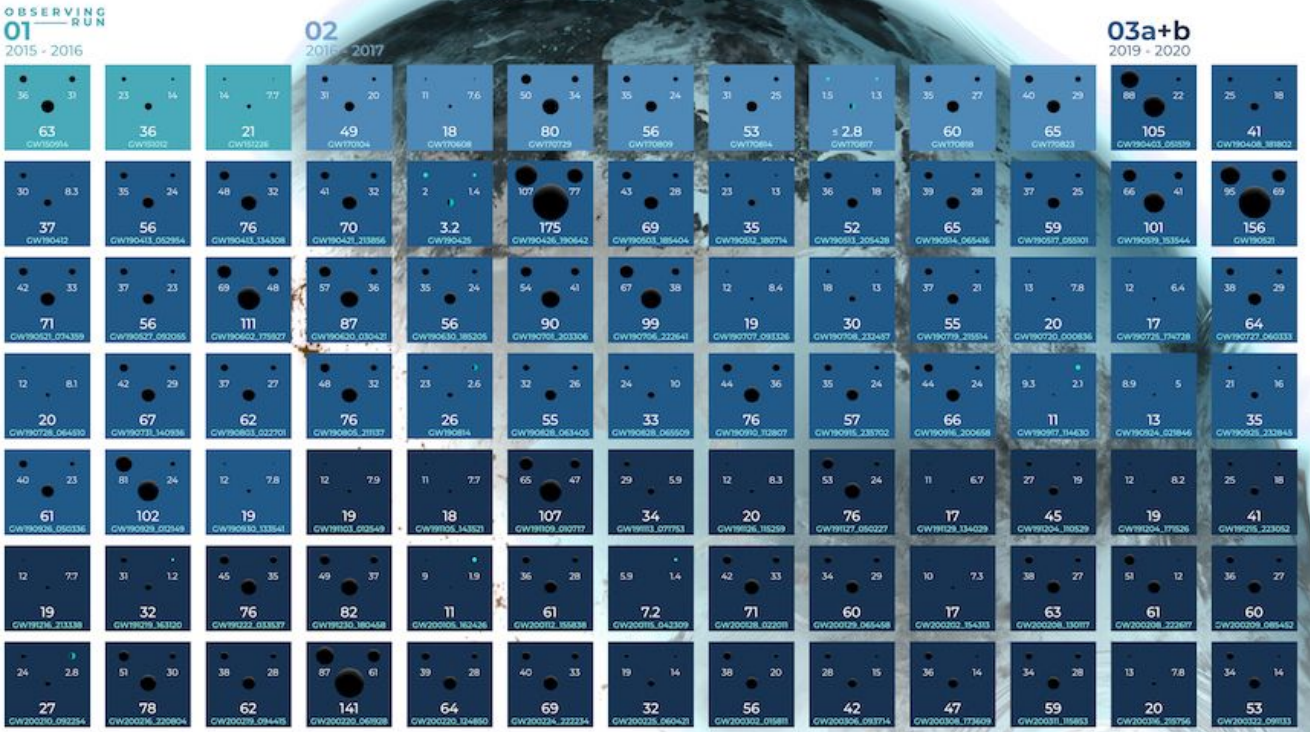
The LVK detector network and collaboration





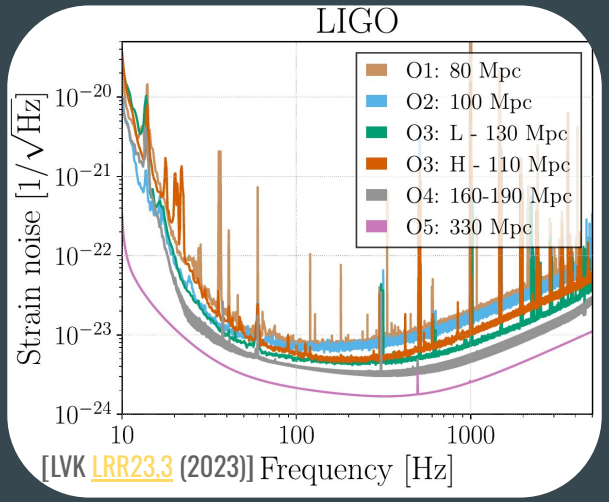


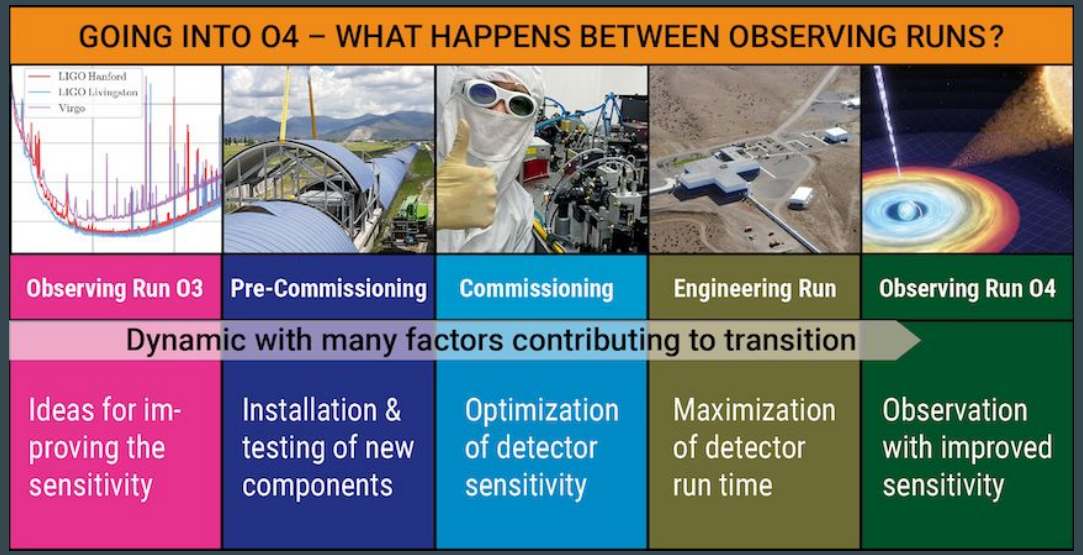
- >2000 scientists from >200 groups on 5 continents
- 52 papers from O3
- 1 from O4 so far


OBSERVING RUN
01
2015 - 2016
02
2016 - 2017
03a+b
2019 - 2020
KEY
BLACK HOLE
NEUTRON STAR
PRIMARY MASS
SECONDARY MASS
FINAL MASS
DATE(_TIME)
UNITS ARE SOLAR MASSES
1 SOLAR MASS = 1.989 x 10^30 kg
GRAVITATIONAL WAVE
MERGER
DETECTIONS
SINCE 2015
OzGrav
LIGO
VIRGO
KAGRA

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, ...
- Exciting challenges ahead for further improving the LVK network and for future detectors!

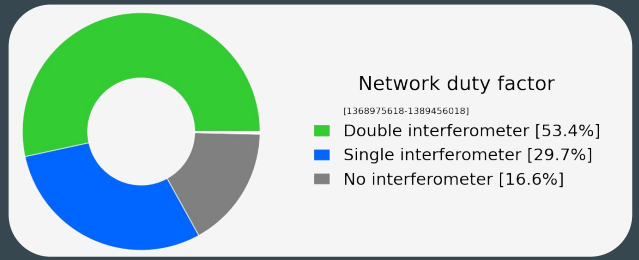


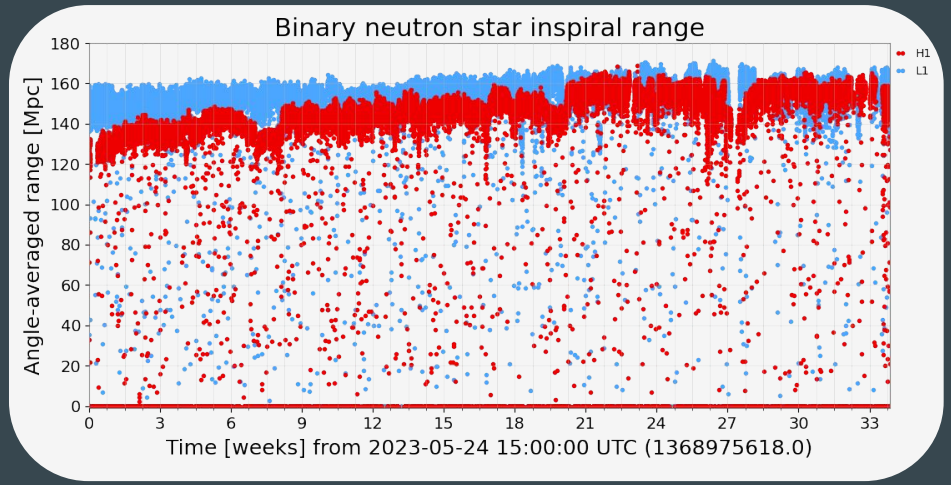


The O4 run so far

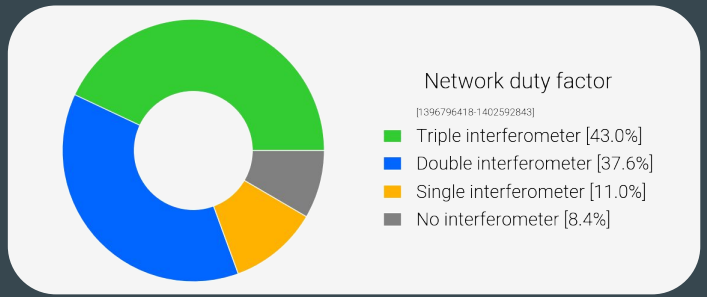
gwosc.org/detector_status/

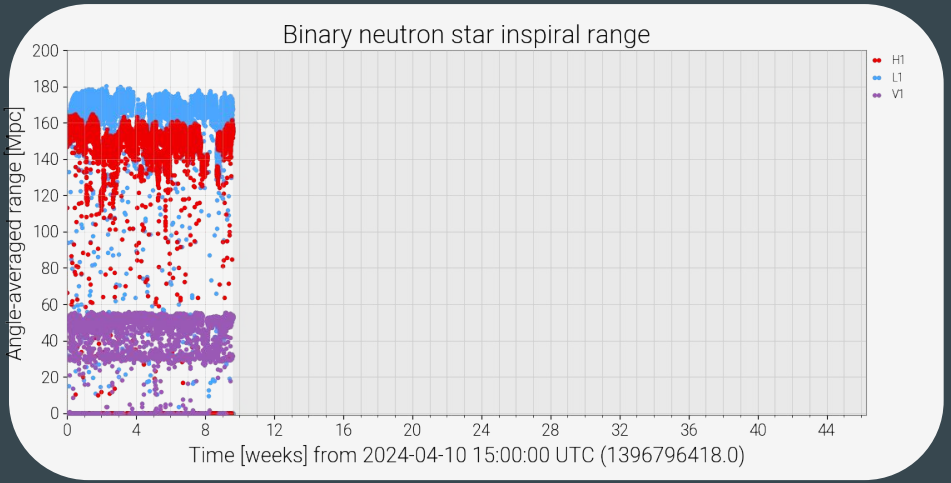
- O4a: 2023/05/27 – 2024/01/16 (LIGO)
  - duty cycles 67.5% (Hanford), 69% (Livingston)





- 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: gracedb.ligo.org | emfollow.docs.ligo.org/userguide | chirp.research.exeter.ac.uk (also mobile apps)

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

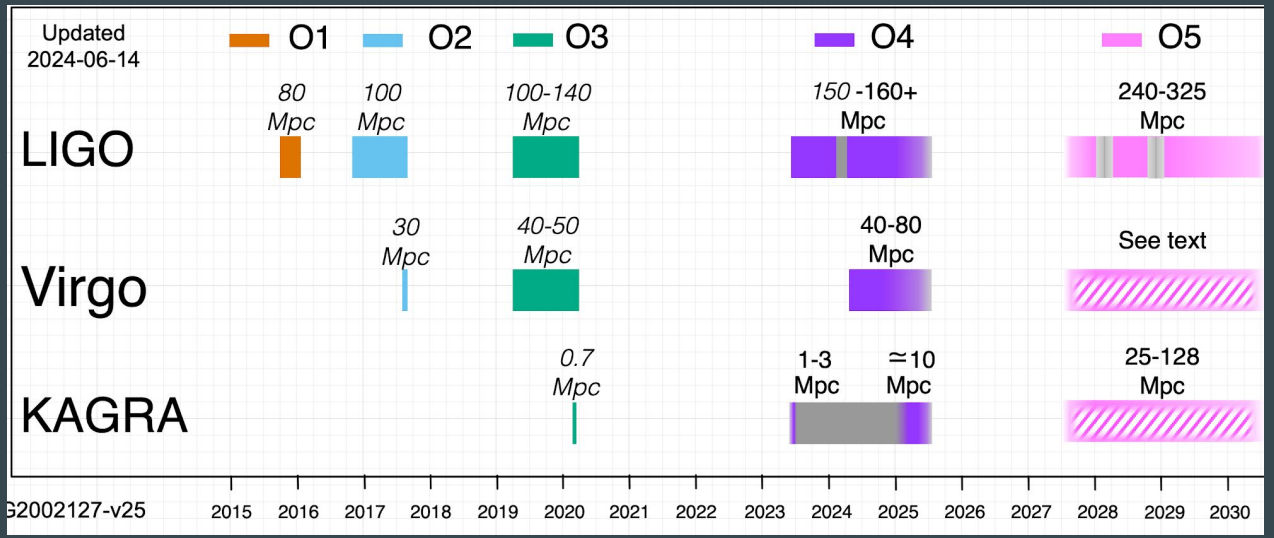
O4 Low Significance Detection Candidates: **2012** (Total) [2024/06/16]

- now also including marginal candidates (to enable deep EM coincidence searches) and BNS pre-merger alerts
- one first event published in detail: GW230529_181500 → 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, ...

O4 extension and O5 schedule

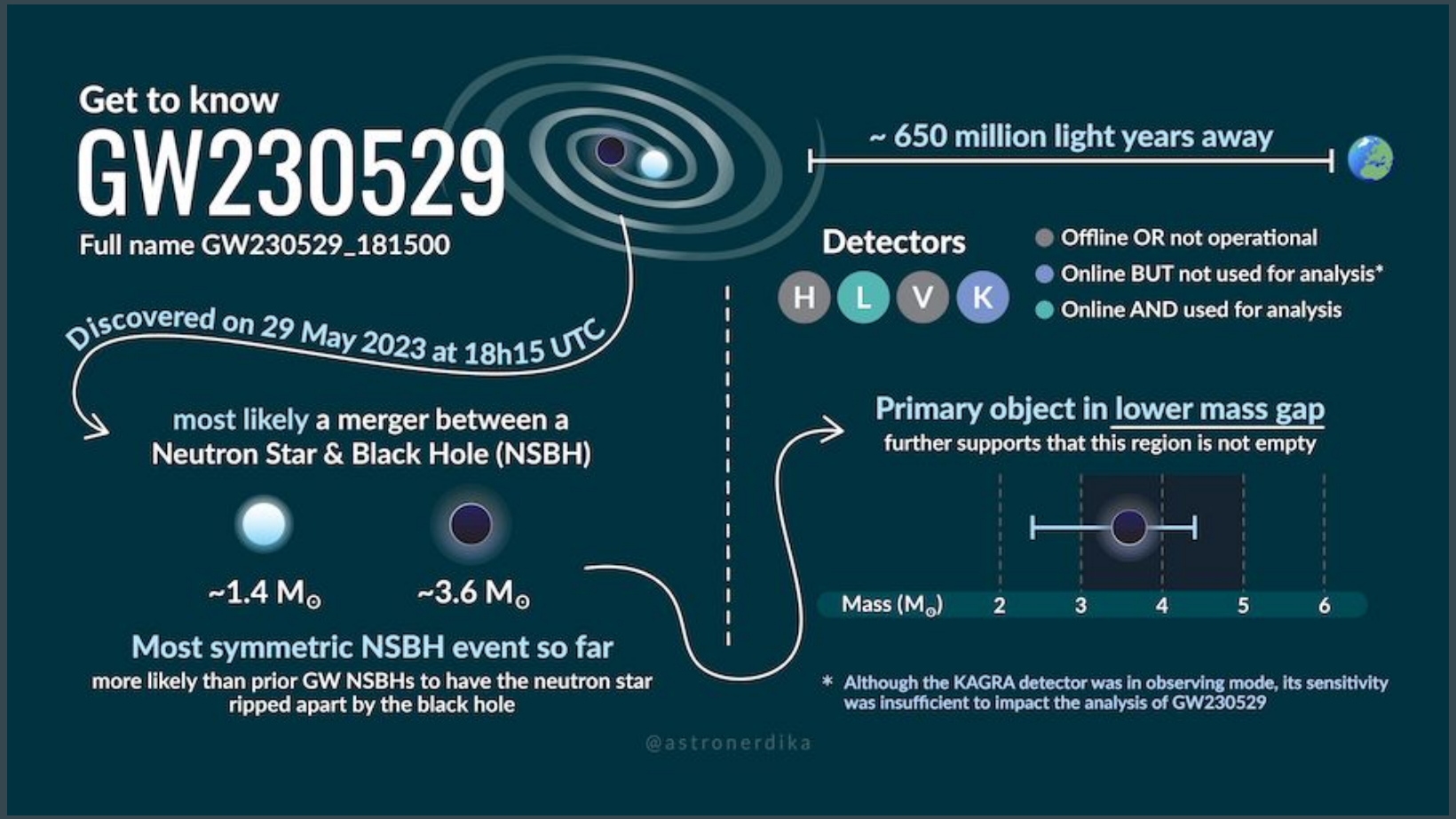
new schedule →
(as of this weekend)



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."*

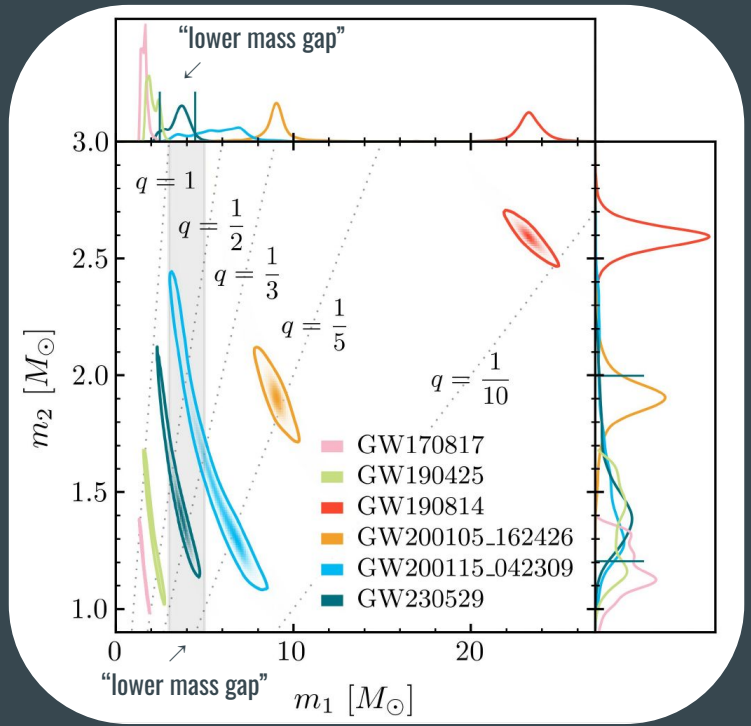
GW230529 [Abac+ (LVK) arXiv:2404.04248]



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 $m_2/M_\odot$	$1.4^{+0.6}_{-0.2}$
Mass ratio $q = m_2/m_1$	$0.39^{+0.41}_{-0.12}$
Total mass $M/M_\odot$	$5.1^{+0.6}_{-0.6}$
Chirp mass $\mathcal{M}/M_\odot$	$1.94^{+0.04}_{-0.04}$
Detector-frame chirp mass $(1+z)\mathcal{M}/M_\odot$	$2.026^{+0.002}_{-0.002}$
Primary spin magnitude χ_1	$0.44^{+0.40}_{-0.37}$
Effective inspiral-spin parameter $\chi_{\rm eff}$	$-0.10^{+0.12}_{-0.17}$
Effective precessing-spin parameter $\chi_{\rm p}$	$0.40^{+0.39}_{-0.30}$
Luminosity distance $D_{\rm L}$/Mpc	201^{+102}_{-96}
Source redshift z	$0.04^{+0.02}_{-0.02}$

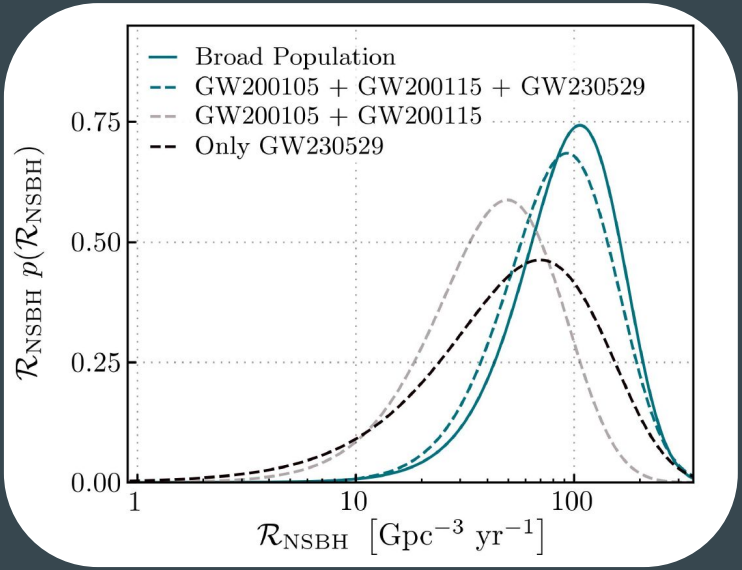


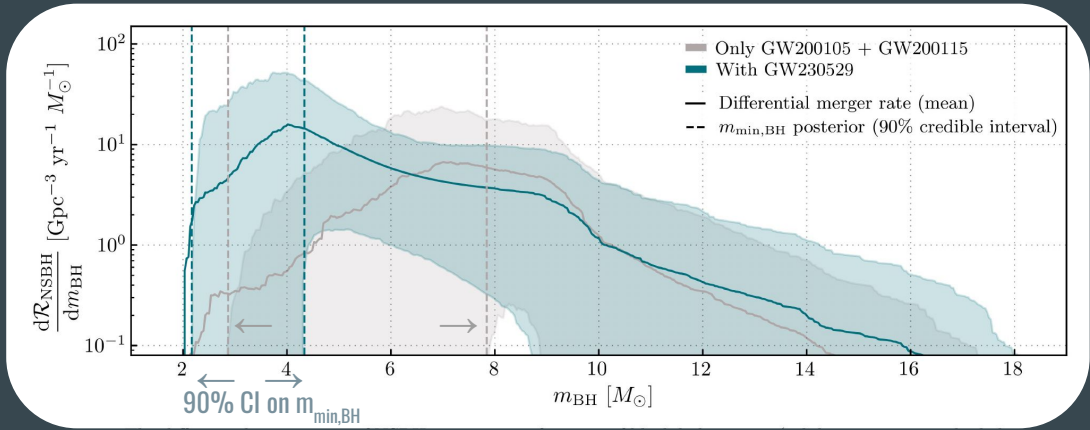
GW230529 [arXiv:2404.04248]

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

	$\chi_1, \chi_2 \leq 0.99$	$\chi_1, \chi_2 \leq 0.05$	Power law + Dip + Break
$P(m_1 \text{ is NS})$	$(2.9 \pm 0.4)\%$	$< 0.1\%$	$(8.8 \pm 2.8)\%$
$P(m_2 \text{ is NS})$	$(96.1 \pm 0.4)\%$	$> 99.9\%$	$(98.4 \pm 1.3)\%$

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

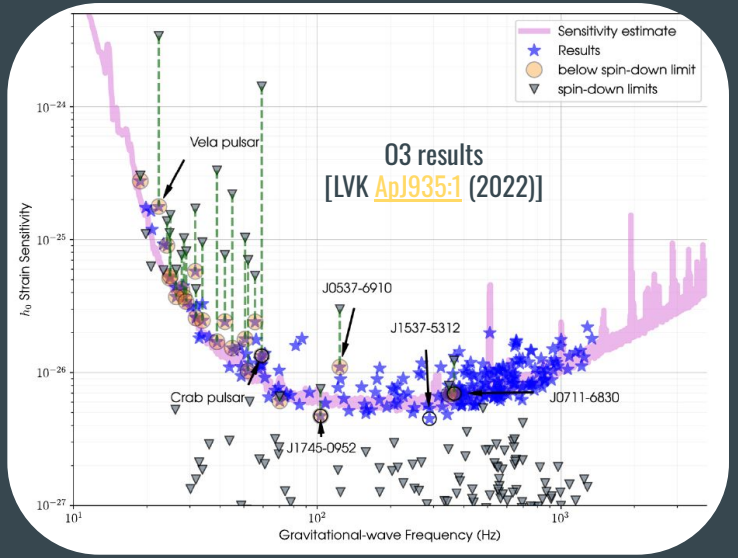


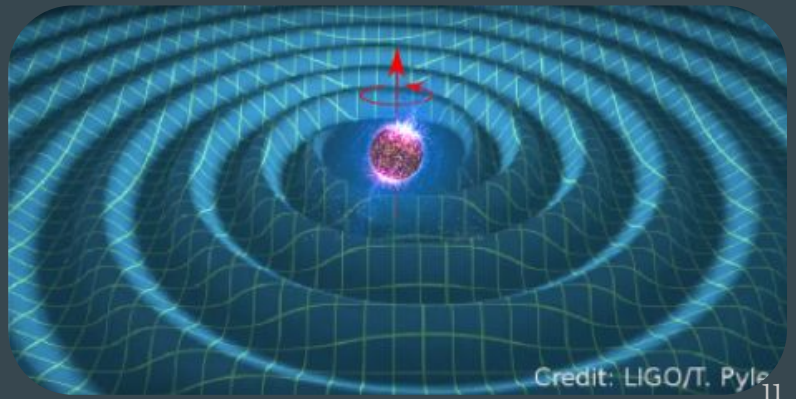


C(G)W O4 plans

LVK OBS white paper 2024:
LIGO-T2300406

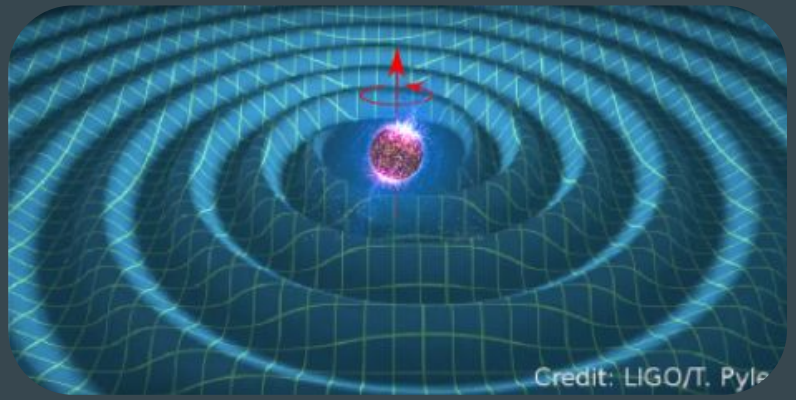
- Known pulsars:
  - targeted (single-template) searches at $f = f_{rot}$ and $f = 2f_{rot}$
  - narrowband searches arround $f = 2f_{rot}$
  - r-mode searches
  - post-glitch long-transient searches
- Directed searches (known sky location, unknown frequency):
  - isolated NSs in galactic supernova remnants
  - 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



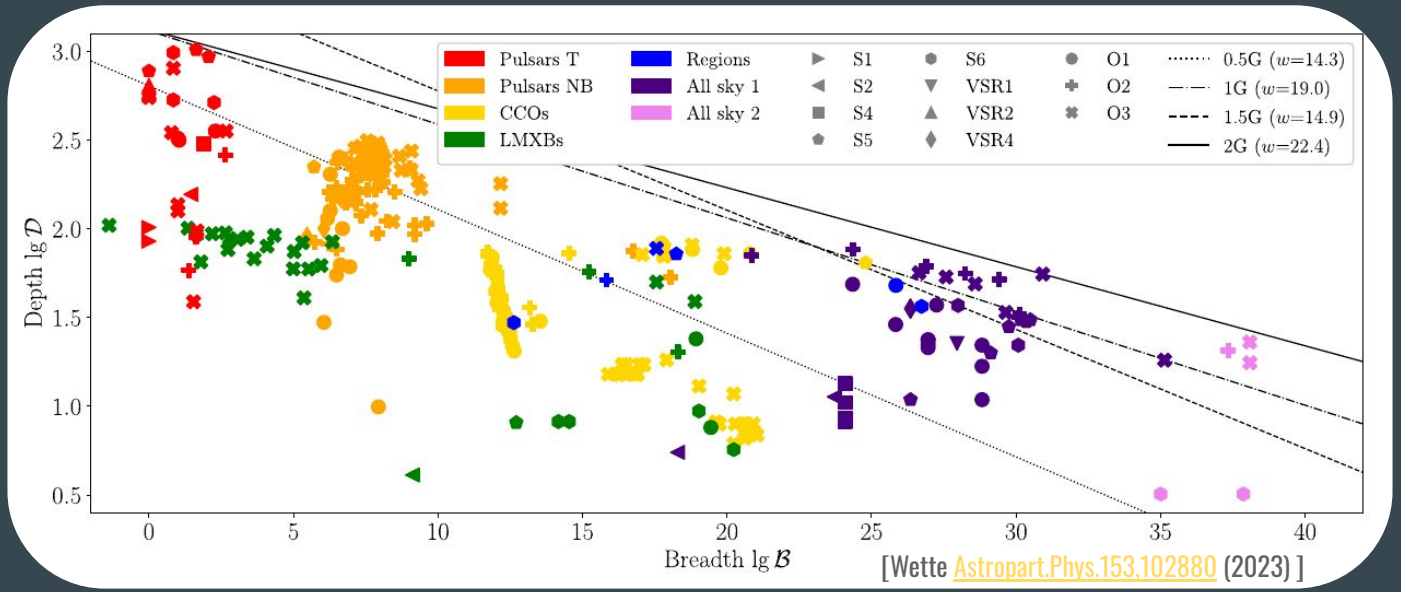


C(G)W O4 plans

LVK OBS white paper 2024:
LIGO-T2300406



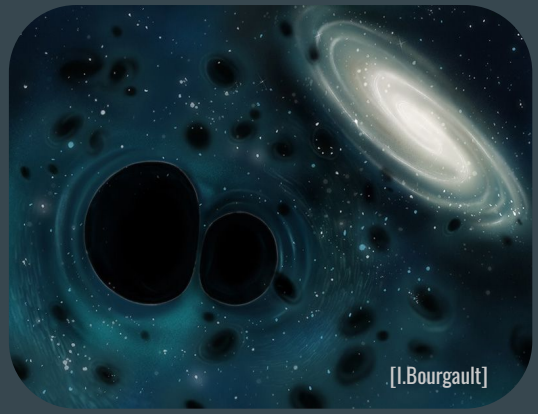
- All-sky searches:
  - unknown isolated NSs
  - unknown generic CW sources
  - unknown NSs in binaries



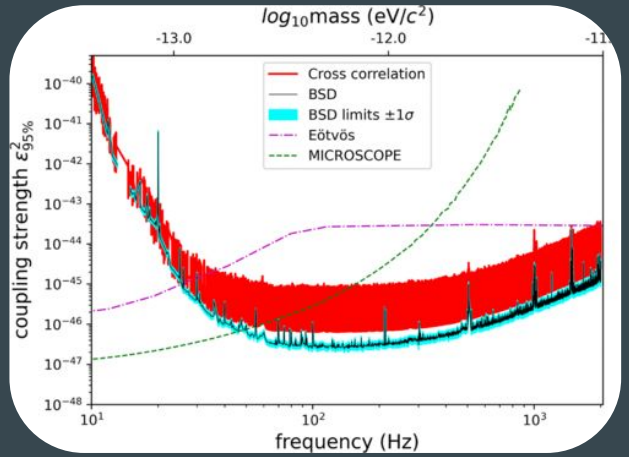
[Wette Astropart.Phys.153,102880 (2023)]

C(G)W O4 plans: new physics

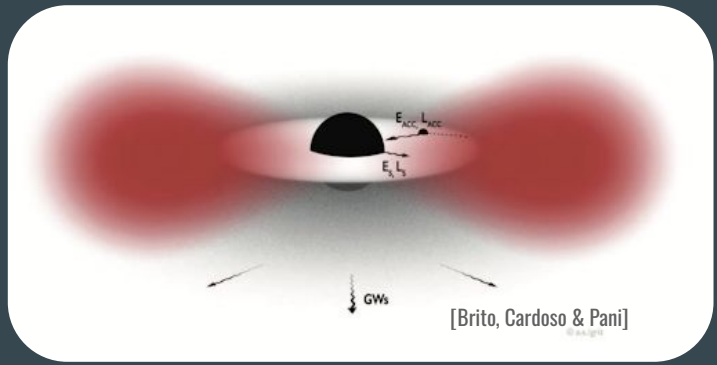
LVK OBS white paper 2024:
LIGO-T2300406



- 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

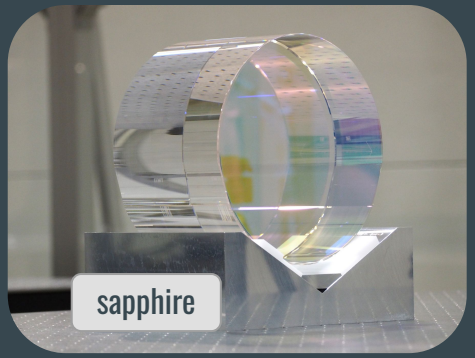


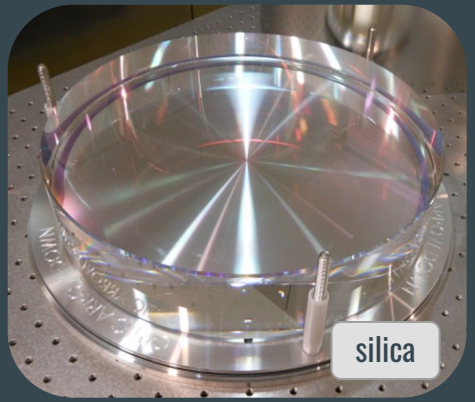
[LVK PRD105.063030 (2022)
– plot updated in recent erratum]

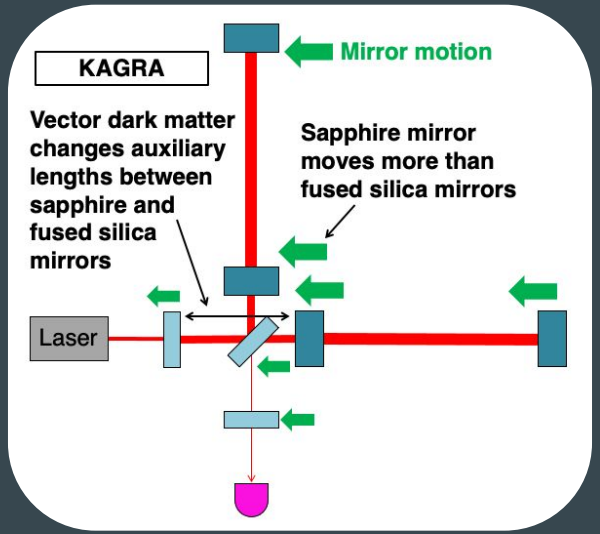


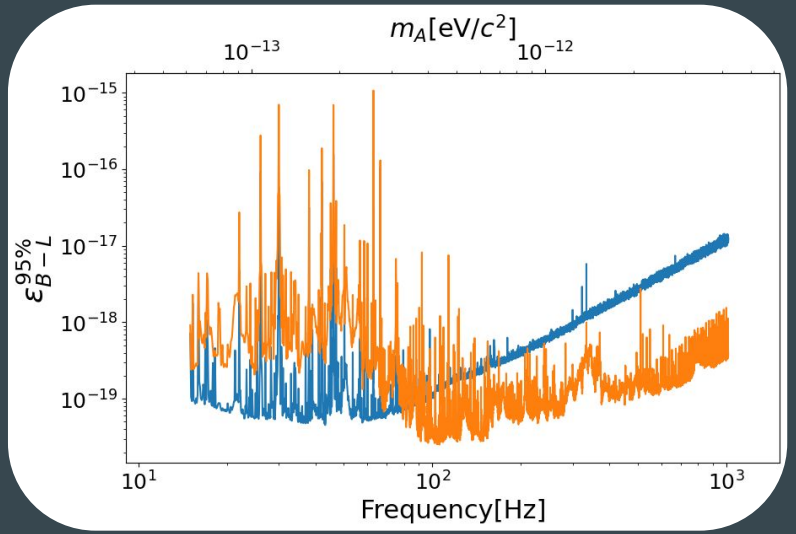
Latest O3 C(G)W result: KAGRA dark matter search

- Abac+ (LVK) arXiv:2403.03004
- 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)



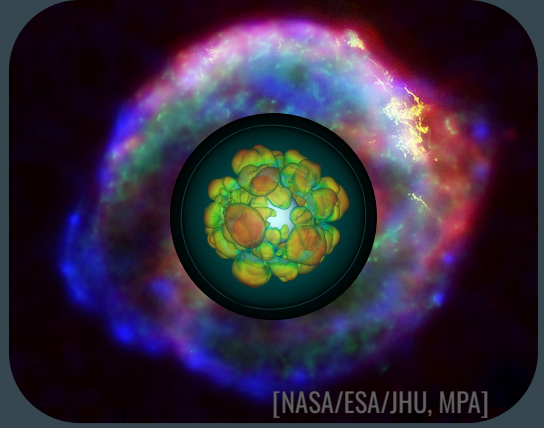


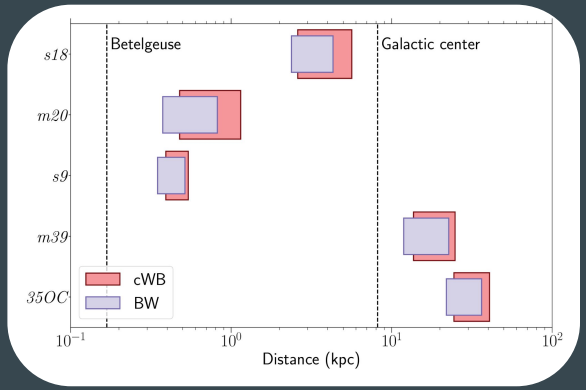




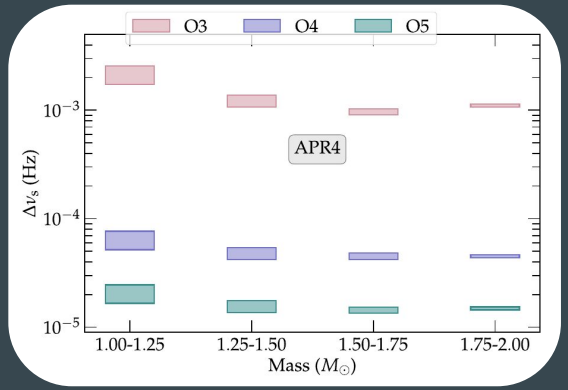
Other GWs from NSs: bursts

- 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, ...


[NASA/ESA/JHU, MPA]



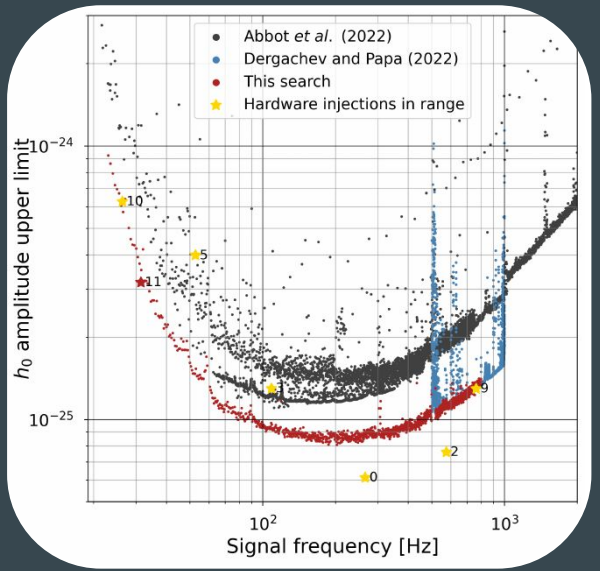
[LVK PRD104,122004 (2021)]



[Lopez+ PRD106,103037 (2022)]

GW open data & software

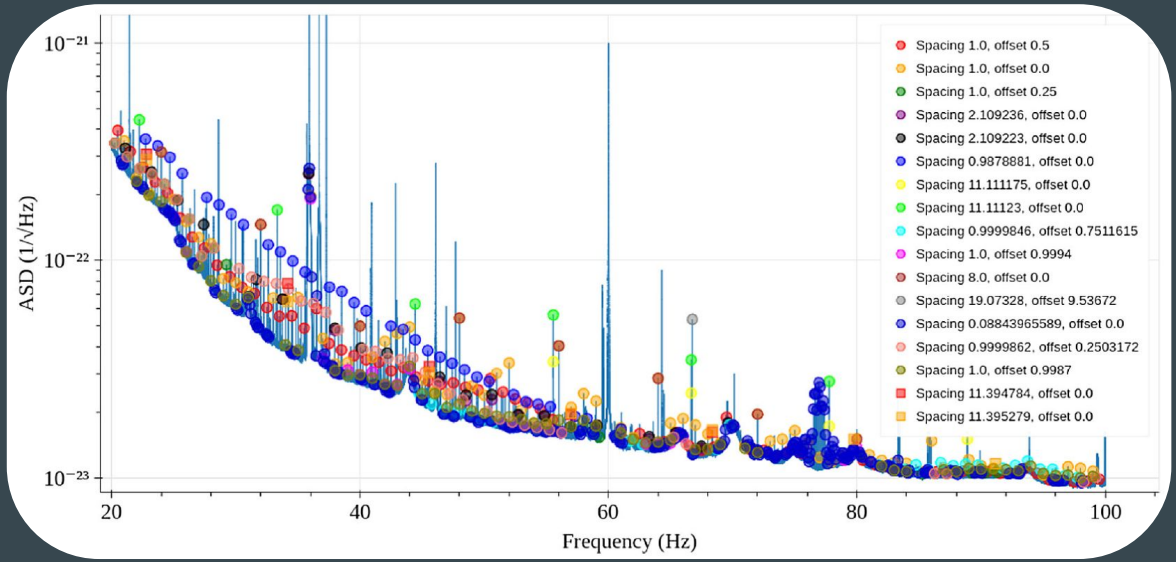
- gwosc.org
- full strain data of observing runs O1–O2 [SoftwareX 13,100658 (2021)] and O3 [ApJS267:29 (2023)]
- posterior samples for all significant events (first O4 release: GW230529)
- Future data release plans: LIGO-M1000066
- Commitment to open-source software:
  - LIGO-M1500244
  - git.ligo.org/explore
  - computing.docs.ligo.org/guide/software/

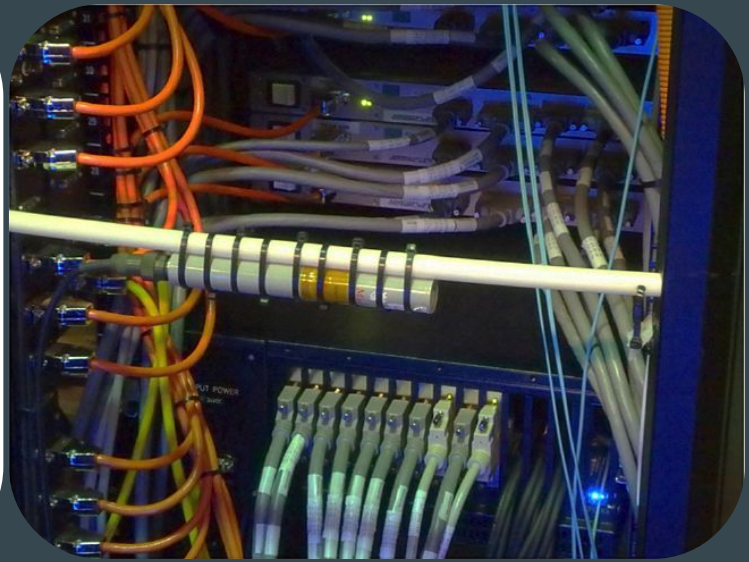


example Einstein@Home usage [Steltner+ ApJ952:55 (2023)]

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.



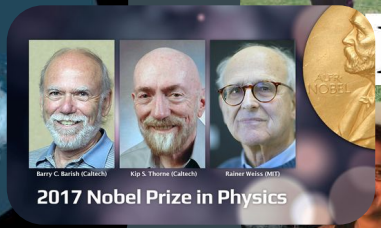


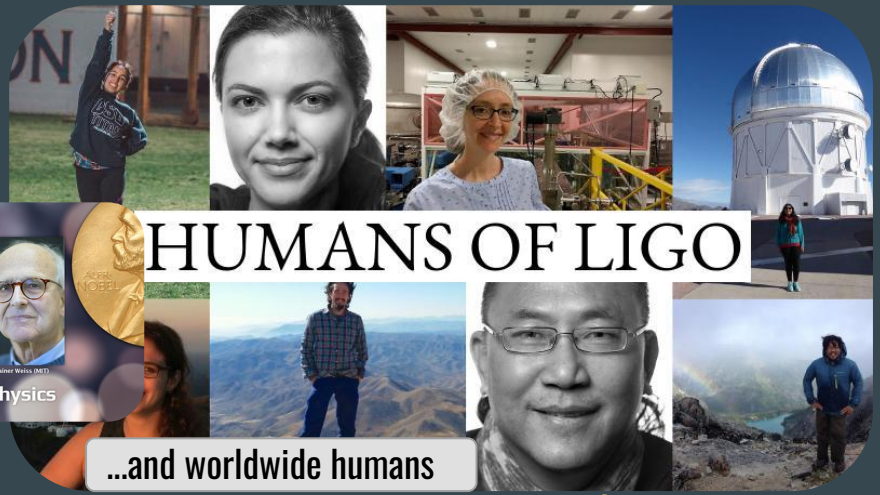
[Covas+ PRD97,082002 (2018)] – O1 era, tools and procedures significantly improved since

Final words

- Through decades of work of a global community, “GW astrophysics” became reality.

Worldwide hardware...





...and worldwide humans

humansofligo.blogspot.com

- 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.
- O4 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

This material is based upon work supported by NSF's LIGO Laboratory which is a major facility fully funded by the National Science Foundation. LIGO Laboratory and Advanced LIGO are funded by the United States National Science Foundation (NSF) as well as the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. Virgo is funded, through the European Gravitational Observatory (EGO), by the French Centre National de Recherche Scientifique (CNRS), the Italian Istituto Nazionale di Fisica Nucleare (INFN) and the Dutch Nikhef, with contributions by institutions from Belgium, Germany, Greece, Hungary, Ireland, Japan, Monaco, Poland, Portugal, Spain. KAGRA is supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Society for the Promotion of Science (JSPS) in Japan; National Research Foundation (NRF) and Ministry of Science and ICT (MSIT) in Korea; Academia Sinica (AS) and National Science and Technology Council (NSTC) in Taiwan.

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