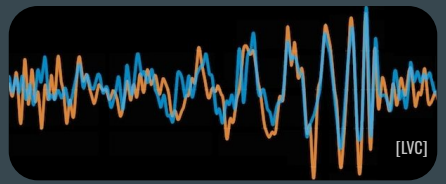
LIGO–Virgo–KAGRA

...

current status and the Spanish role in its future



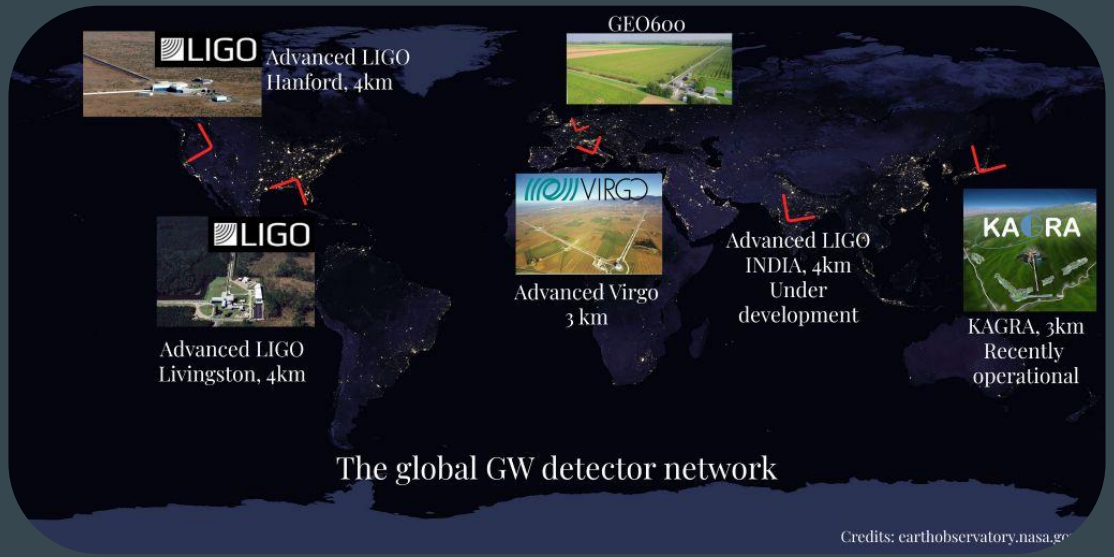
David Keitel (Universitat de les Illes Balears)

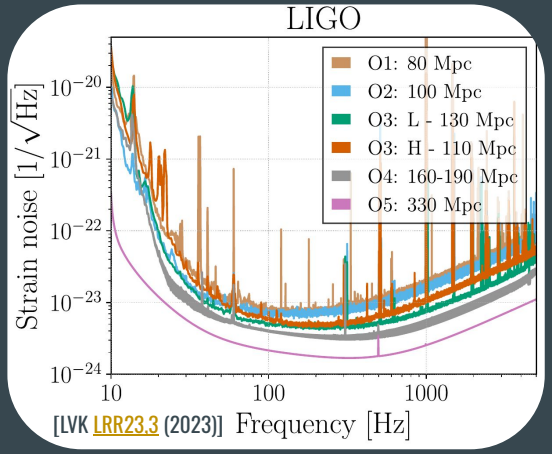
for the LIGO Scientific Collaboration, Virgo Collaboration and KAGRA Collaboration

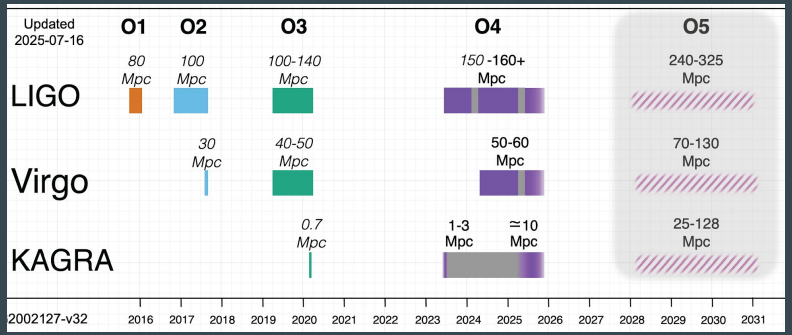
RENATA meeting,
Zaragoza, 2025-09-22

LIGO-G2502040-v5

The LVK detector network and collaboration

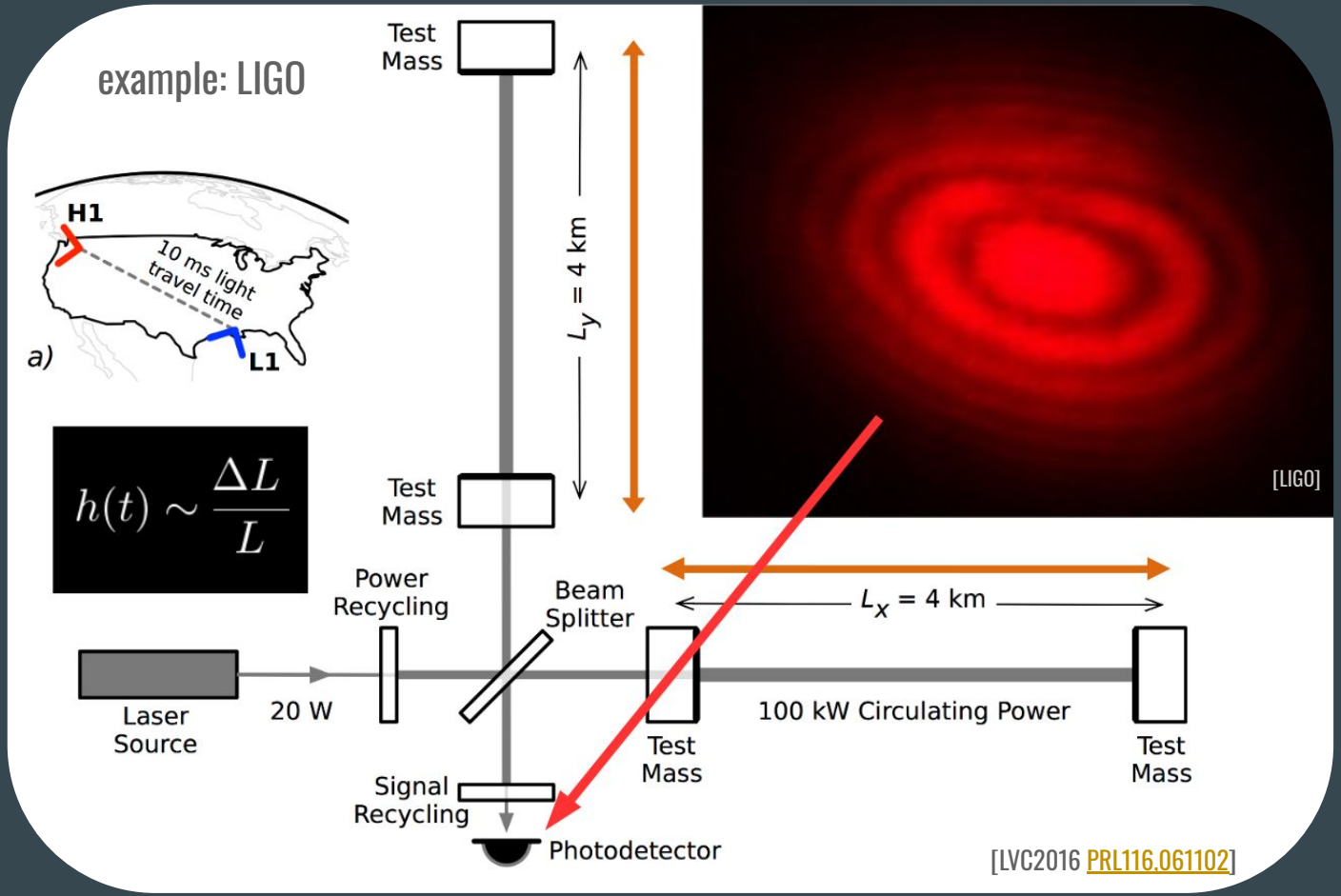






- >2500 scientists from >200 groups on 5 continents
- 53 papers from O3
- 17 from O4 so far

LVK detectors



Note: O1 era graphic!

Laser power has since increased, O4 laser offers max input power 125 W.

Many other improvements, including

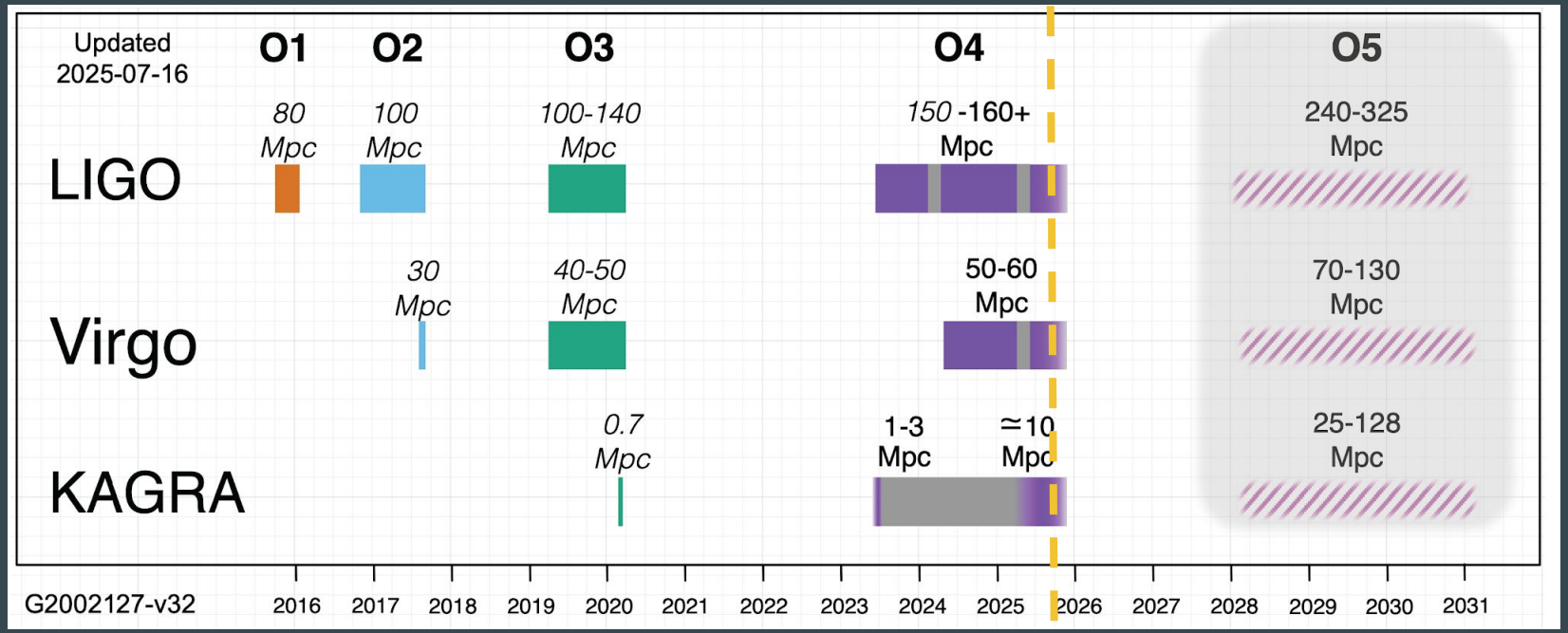
- new test masses
- frequency-dependent squeezing
- various noise mitigations
- ...

[Capote+2025 PRD111,062002]

Virgo: Acernese+2015 CQG32,024001

KAGRA: Akutsu+2021 PTEP,2021,05A101

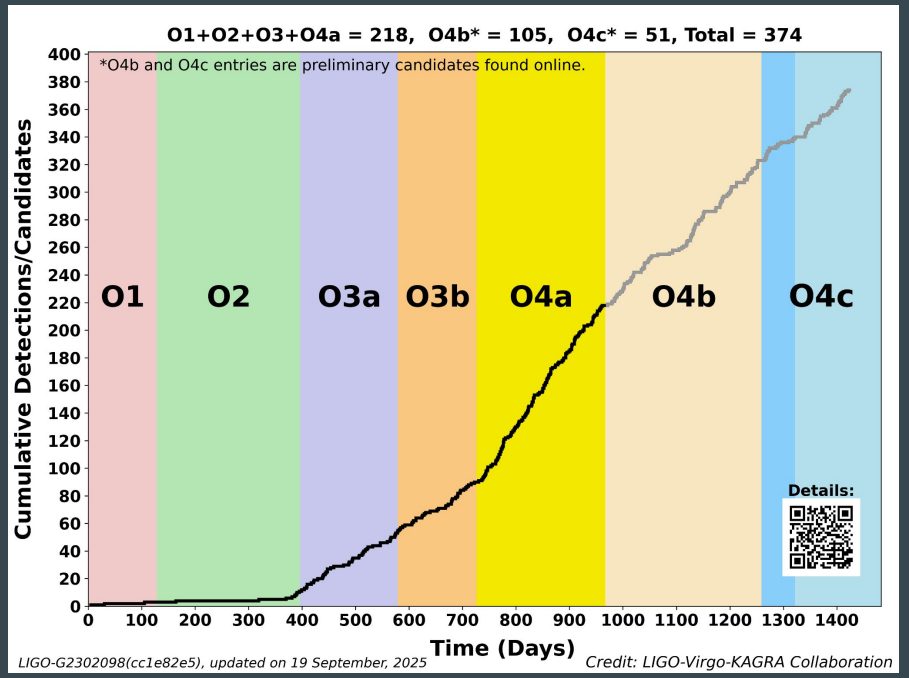
LVK timeline update

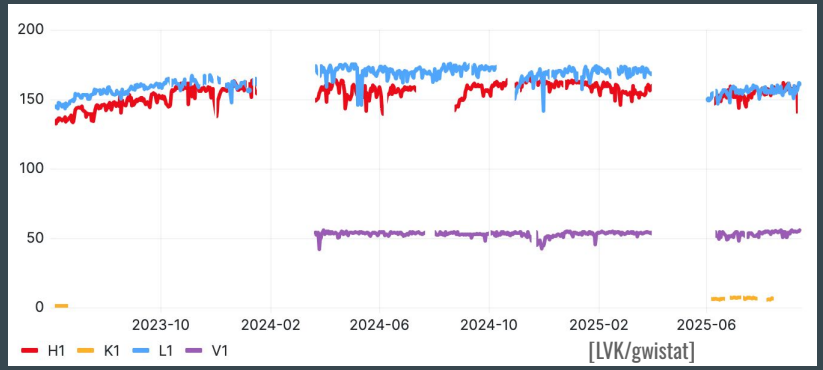


- 2025-08-26: O4a data release → gwosc.org/O4/O4a (O4b, O4c in 2026)
- 2025-11-18: current planned O4 end date
- O5: under reassessment (following US budget considerations, Virgo upgrade plans, etc)

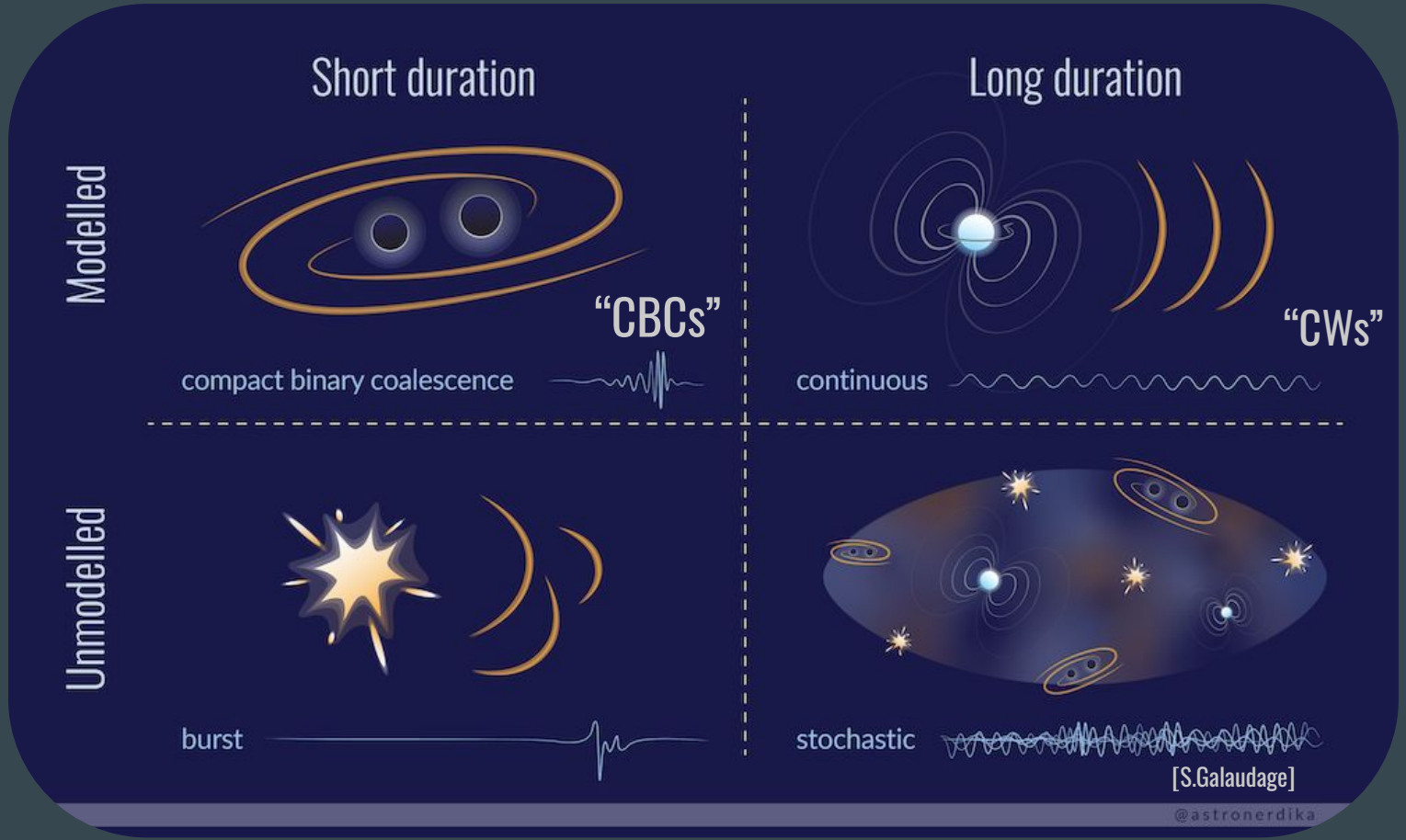
The O4 run so far gwosc.org/detector_status

- O4a: 2023/05/27 – 2024/01/16 (LIGO)
- O4b: 2024/04/10 – 2025/01/28 (LIGO+Virgo)
- O4c: 2025/01/28 – 2025/11/18 (LIGO+Virgo+KAGRA)
- public alerts: 237 high- and 4665 low-significance until 2025-09-19 [gracedb.ligo.org | emfollow.docs.ligo.org/userguide | chirp.research.exeter.ac.uk (also mobile apps)]
- no promising EM/ν counterparts yet
- BNS inspiral ranges up to:
  - LIGO Livingston: ~180 Mpc
  - LIGO Hanford: ~160 Mpc
  - Virgo: ~55 Mpc
  - KAGRA: ~7 Mpc

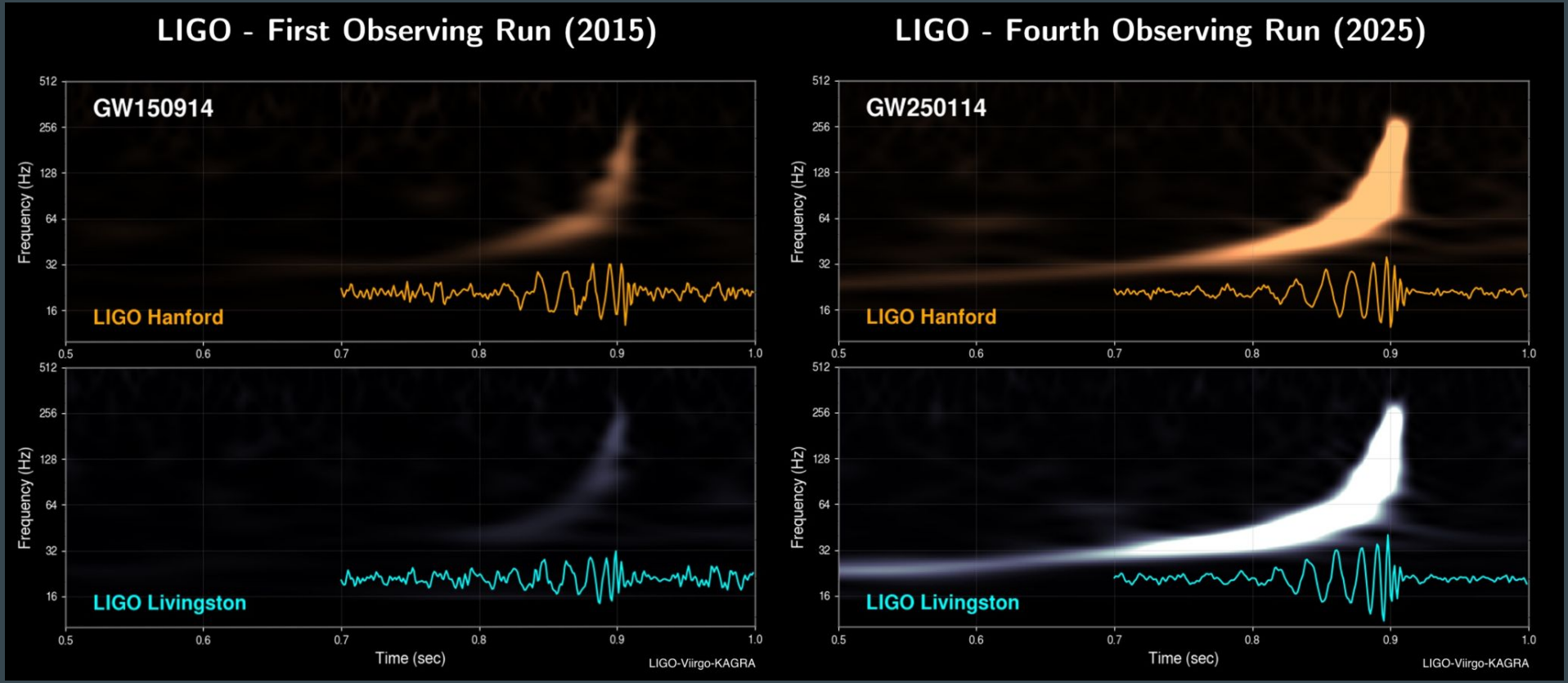




LVK search types



The first decade of CBC observations

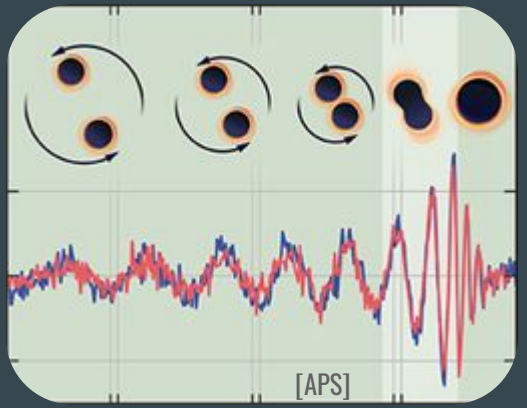


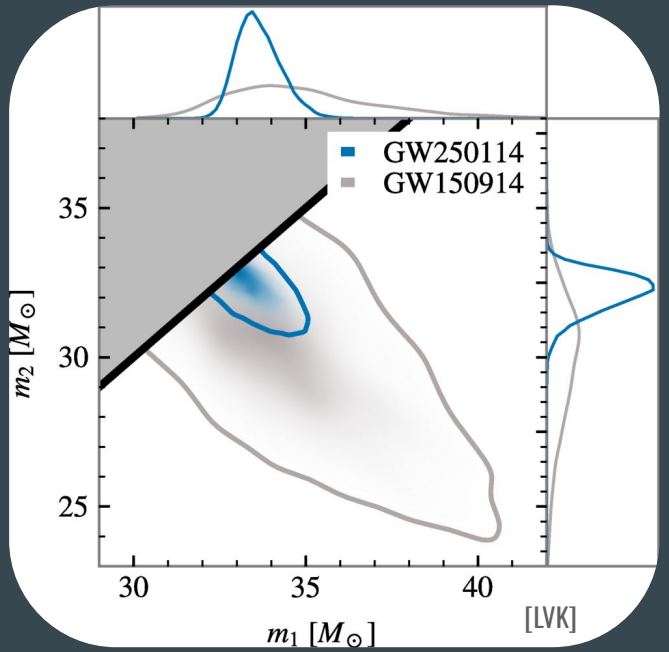
[Phys. Rev. Lett. 116, 061102 (2016)]

[Phys. Rev. Lett. 135, 111405 (2025)]

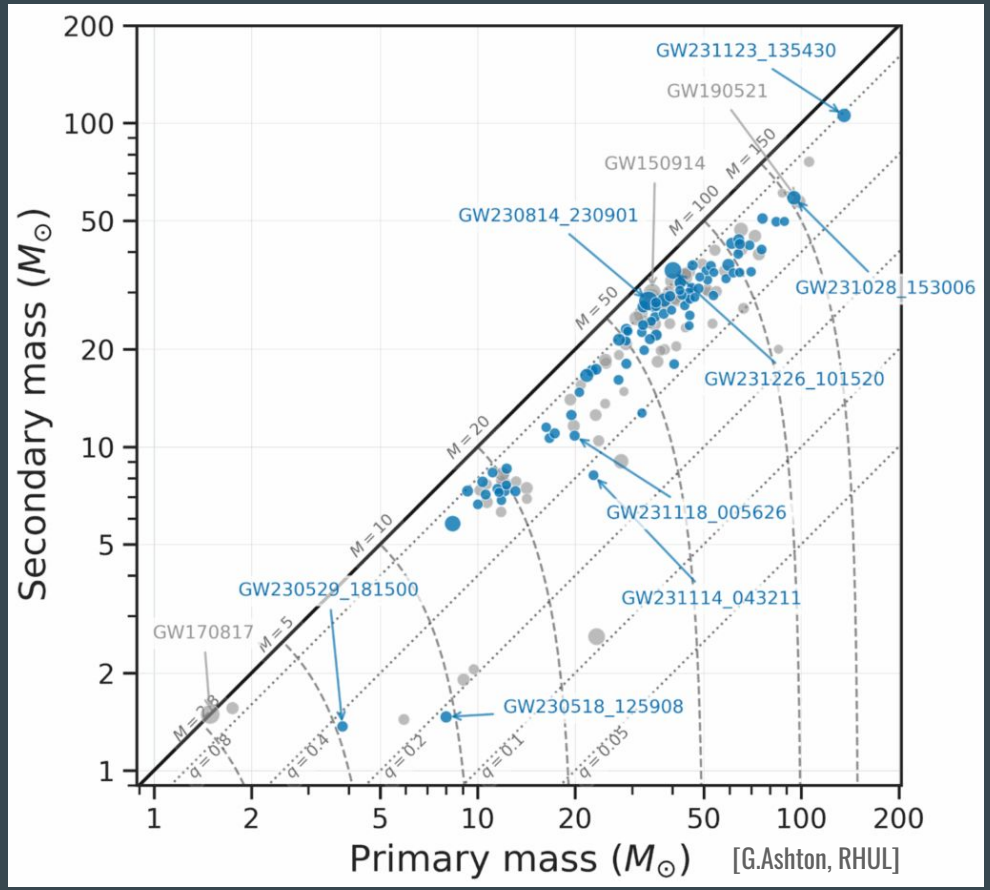
GW250114

- Very similar events: $m_{1,2}$ ~ 30 $M_\odot$, spins ~ 0, d_L ~ 400 Mpc ⟶ same amplitude ~10^{-21}
- GW150914 in O1: SNR~24, GW250114 in O4b: SNR~80!
- GW150914: “Einstein was right!”
- GW250114: “Hawking was right, too!”
- evidence for first ringdown overtone at 4.1 σ
- consistent with Hawking’s area theorem (remnant event horizon area > sum of progenitor areas) with 3–5 σ significance
  (depending on how conservative to be with where to start the ringdown analysis)
- Phys. Rev. Lett. 135, 111405 (2025)
  + arxiv.org/abs/2509.08099



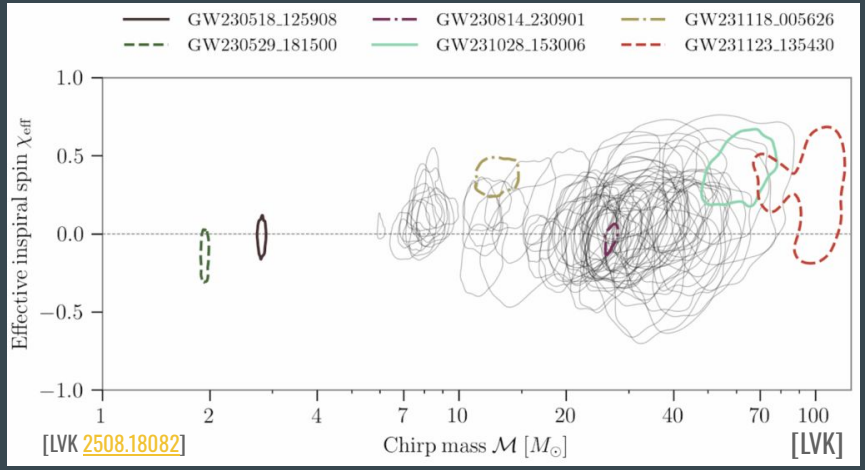


The first decade of CBC observations



GWTC-4.0: arxiv.org/abs/2508.18082

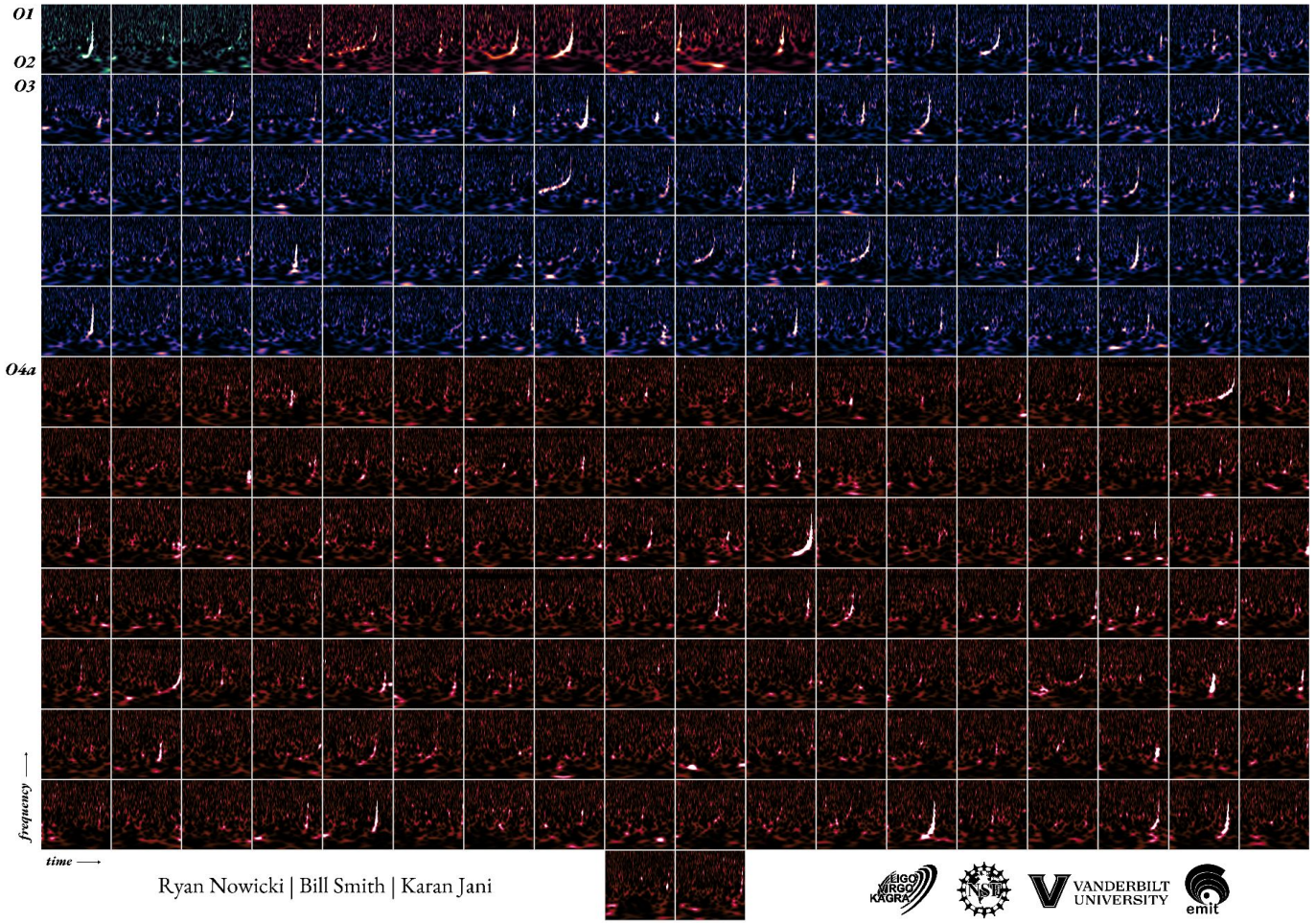
- 218 events with p_{astro}>0.5 (and not otherwise vetoed)



...and never forgotten: GW170817!

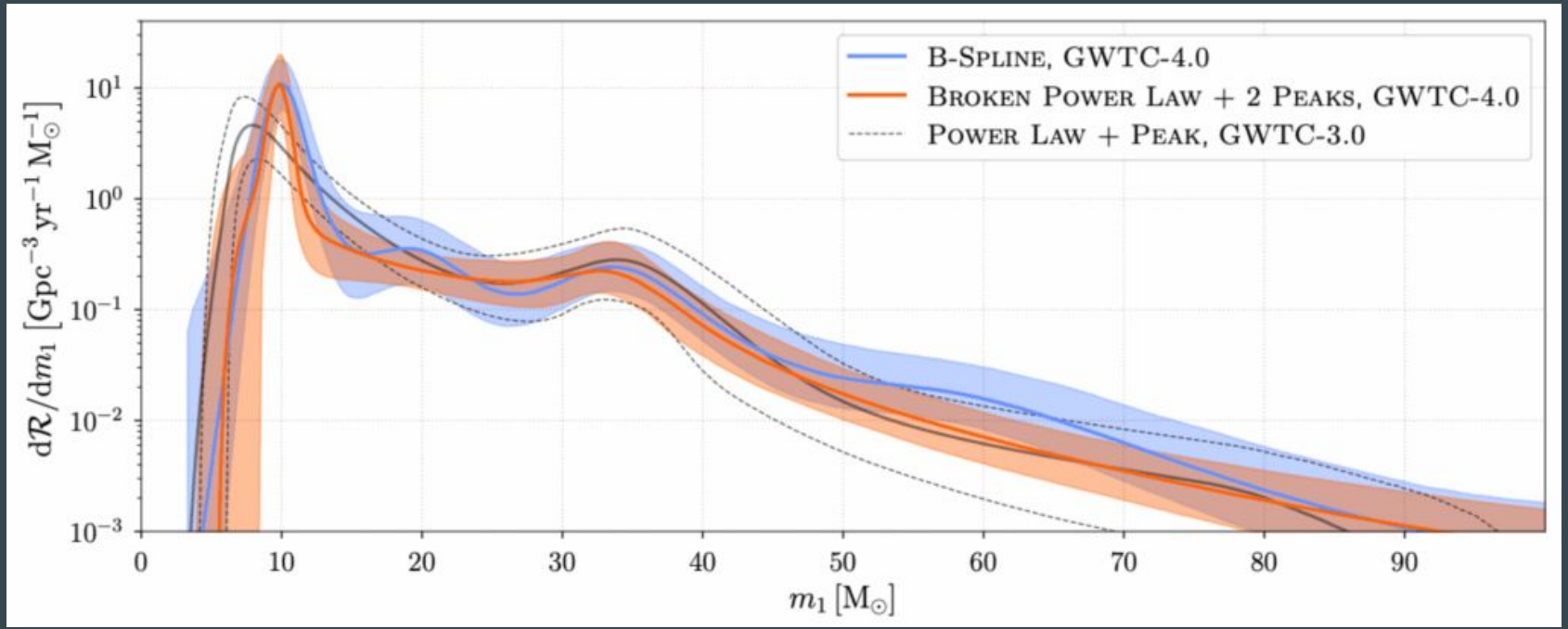
Still the only multi-messenger BNS merger detection.

The first decade of CBC observations



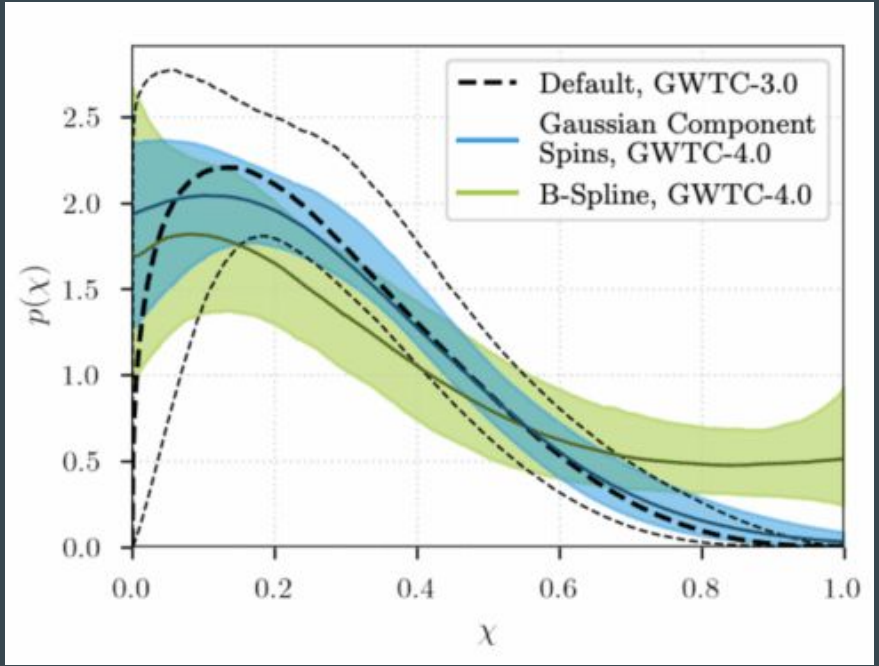
CBCs: recent implications [arxiv.org/abs/2508.18083]

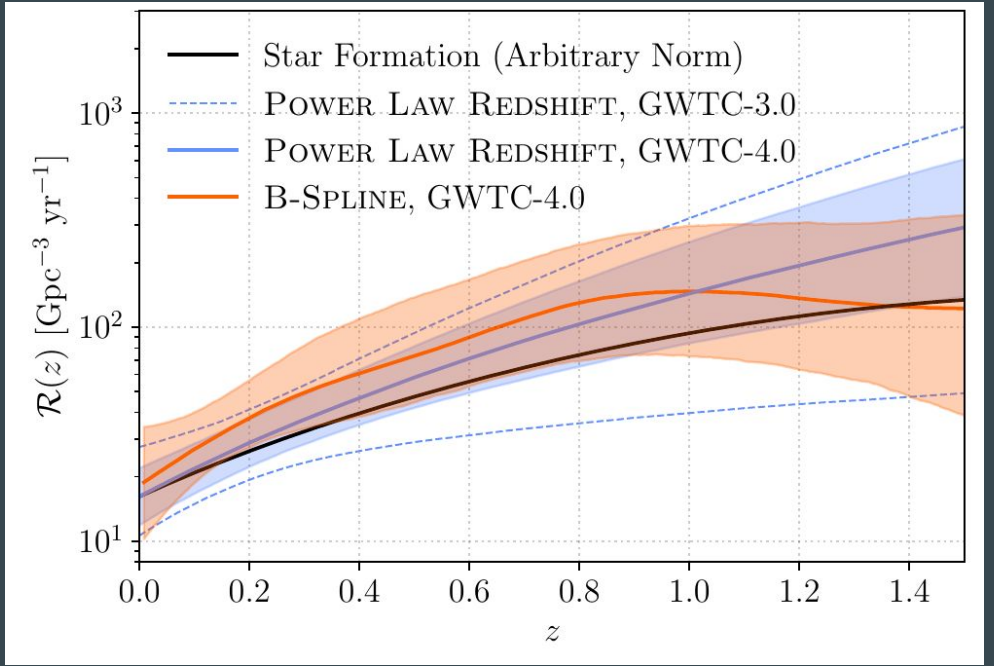
- increasingly sharp picture of rate and mass distribution of merging BBHs:



CBCs: recent implications [arxiv.org/abs/2508.18083]

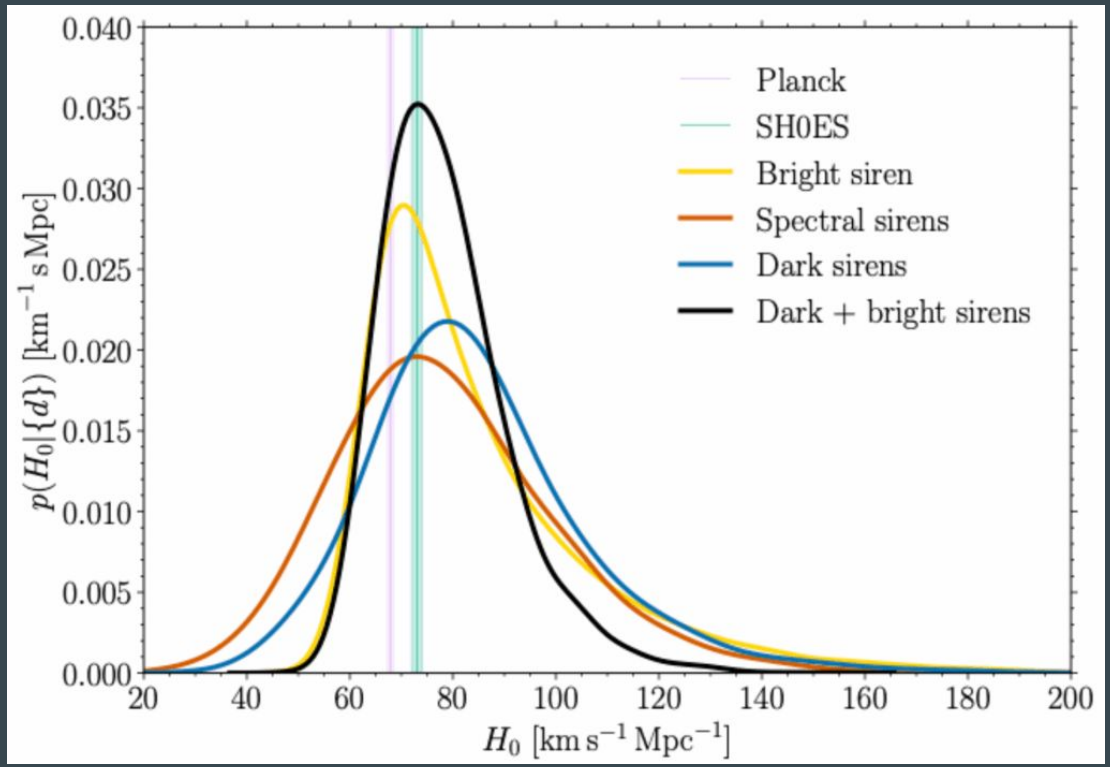
- also beginning to constrain spin distribution and rate evolution with redshift





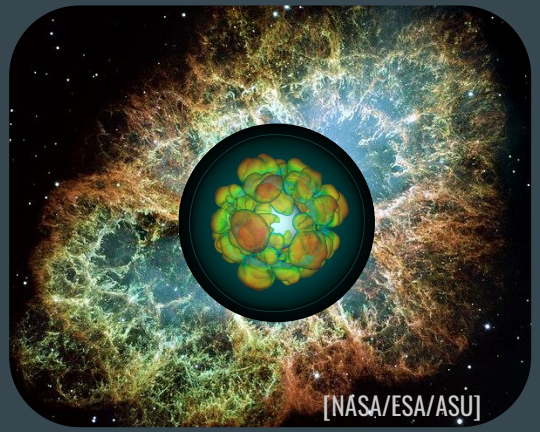
CBCs: recent implications [arxiv.org/abs/2509.04348]

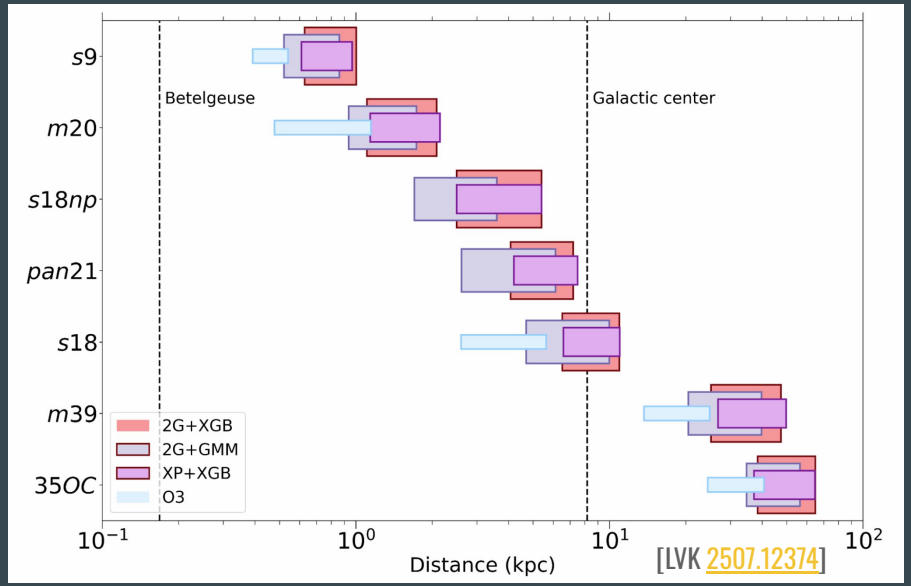
- cosmographic inference:



Beyond CBCs: GW bursts

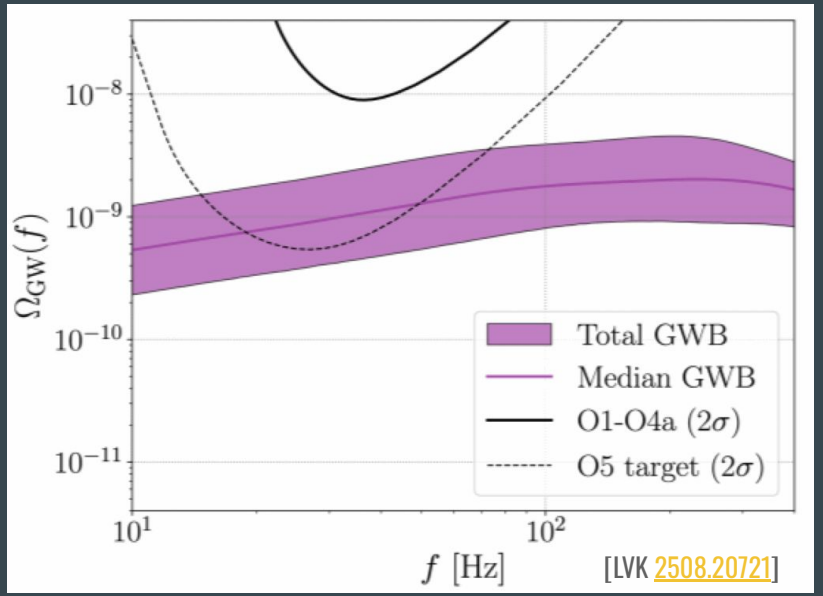
- less well-modeled GW transients: eccentric BBHs, supernovae, magnetars, cosmic strings, ...
- search with more generic methods: excess power, pattern recognition, ...
- no detections so far (besides BBHs)
- non-detections can still yield physical constraints: nearby supernovae, glitching pulsars, ...
- O4a all-sky results: 2507.12282 + 2507.12374





Beyond CBCs: stochastic GWs

- Astrophysical backgrounds:
  overlap of faint, unresolved CBCs
  → should be within reach at O5 sensitivity



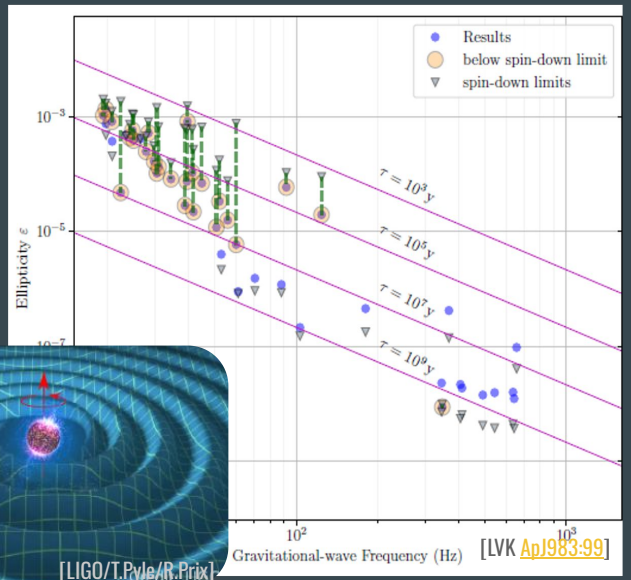
[LVK 2508.20721]

- Cosmological backgrounds = early-universe physics:
  inflationary tensor modes, phase transitions, …
  → estimates very model-dependent, but enormous discovery potential

- Shout-out to Pulsar Timing Arrays! [IPTA ApJ966:105 (2024)]

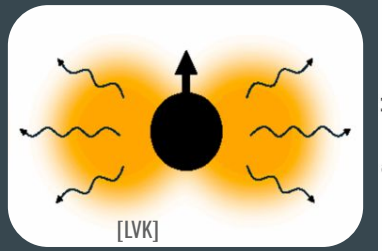
Beyond CBCs: continuous GWs (CWs)

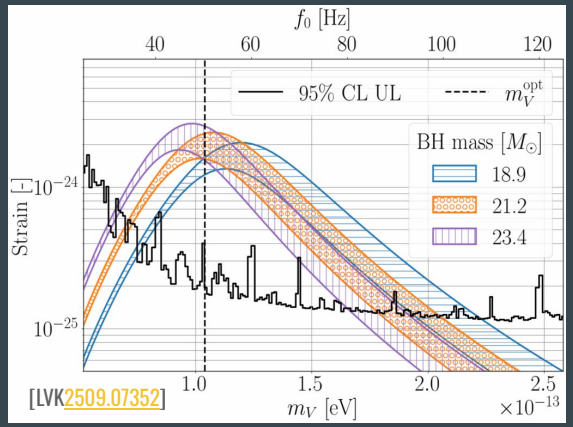
- faint ($h \lesssim 10^{-25}$), long duration, quasi-monochromatic
- extreme computational challenges
- Main target: spinning deformed neutron stars, e.g. O4a known pulsar search [ApJ983:99]



...for dark matter detection

- indirect DM searches: e.g. O4a vector boson clouds [2509.07352]





- Direct DM searches: e.g. O3 LIGO [PRD105.063030], KAGRA [PRD.110.042001]

LVK: Spanish contributions

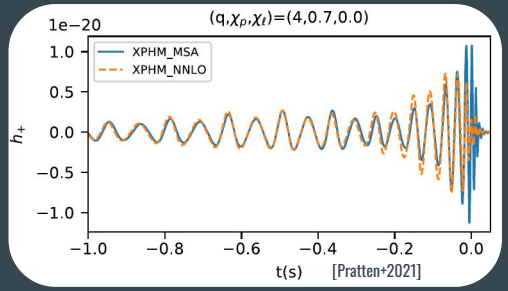
CIEMAT, ICREA, IEEC, IFAE, UAM, UB, UIB, UPM, USC, UV, ...

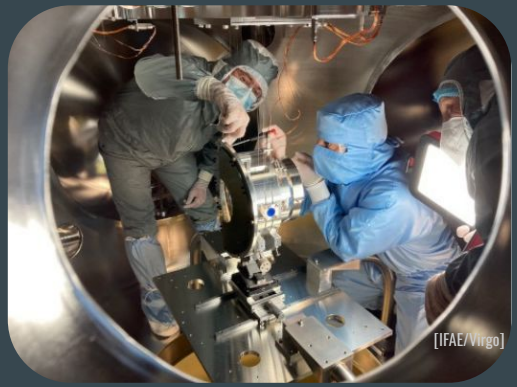
- data analysis:
  - waveform modeling (IMRPhenom program led by UIB)
  - all search types: CBCs, CWs, bursts, stochastic
  - numerical relativity and hydrodynamical simulations
  - high-performance computing
  - Bayesian parameter estimation and population inference
  - Electromagnetic counterparts

[I probably forgot something!]

- detector characterization and commissioning
  (incl. LIGO fellows / Virgo site visits)
- instrumentation: e.g. Virgo baffles (ICREA) and vacuum pumps (UV)
- leadership roles:
  - A. Font (UV): Virgo editorial committee chair
  - I. Cordero (UV): former Virgo outreach coordinator
  - A. Sintes (UIB) LSC Speakers and Awards Committee
  - D. Keitel (UIB): CW co-chair, A. Ramos-Buades (UIB): CBC waveforms chair
  - M. Martinez (ICREA): IGWN design committee, LVK meeting 2024/09 host

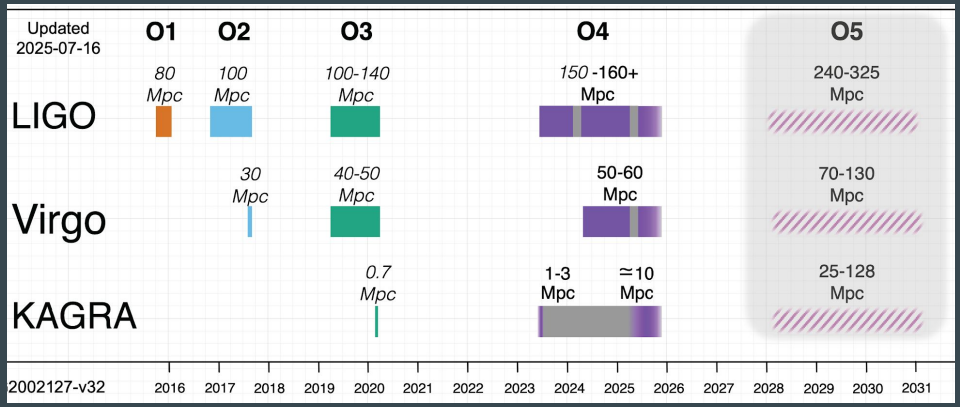
[I probably forgot someone!]





The future: O5 and beyond, IGWN

observing.docs.ligo.org/plan/



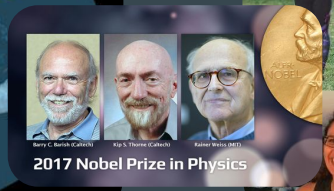
- O4 until 2025-11-18 (?)
- O5 starting in 2027 (?)
  → 3+ years run (?)

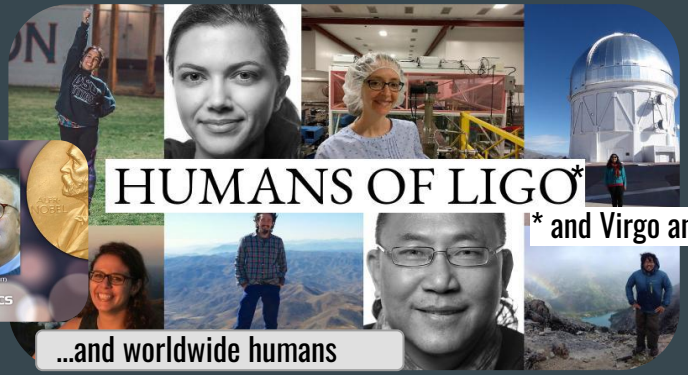
- big change, and an opportunity for Spain:
  International Gravitational-Wave Observatory Network (**IGWN**, 2026+) → https://www.igwn.org
- one global collaboration instead of LVK "collaboration of collaborations"
- key objective: resolve long-standing personnel shortfall in essential operational activities (computing support, detector calibration and characterisation, key data products)
- need for more consolidated national contributions to operational activities
- global "IGWN [Funding] Agency Oversight Committee" – *personal opinion: Spain should have a seat!*

Final words

More questions later?
→ david.keitel@ligo.org

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





humansofligo.blogspot.com

- Rich science returns from 1st decade of CBC detections: unprecedented insights into the physics, populations and evolutionary history of compact objects in our universe.
- Many other science targets are within reach: CWs, bursts, stochastic backgrounds, dark matter.
- O4 providing the best sensitivity and longest run duration yet.
- The global detector network continues to improve and grow; possibilities to dovetail with ET/CE.
- Need for a consolidated Spanish effort 🇪🇸 for a strong position in IGWN

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.

David Keitel is supported by the Universitat de les Illes Balears (UIB); the Spanish Agencia Estatal de Investigación grants CNS2022-135440, PID2022-138626NB-I00, RED2024-153978-E, RED2024-153735-E, funded by MICIU/AEI/10.13039/501100011033, the European Union NextGenerationEU/PRTR, and the ERDF/EU; and the Comunitat Autònoma de les Illes Balears through the Conselleria d'Educació i Universitats with funds from the European Union - NextGenerationEU/PRTR-C17.I1 (SINCO2022/6719) and from the European Union - European Regional Development Fund (ERDF) (SINCO2022/18146). Special thanks to the RENATA organisers for the invitation!