Results from the LIGO-Virgo-KAGRA Fourth Observation

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The third annual conference of Transformative Research Areas (A) “Multimessenger Astrophysics” @Naruko Kanko Hotel

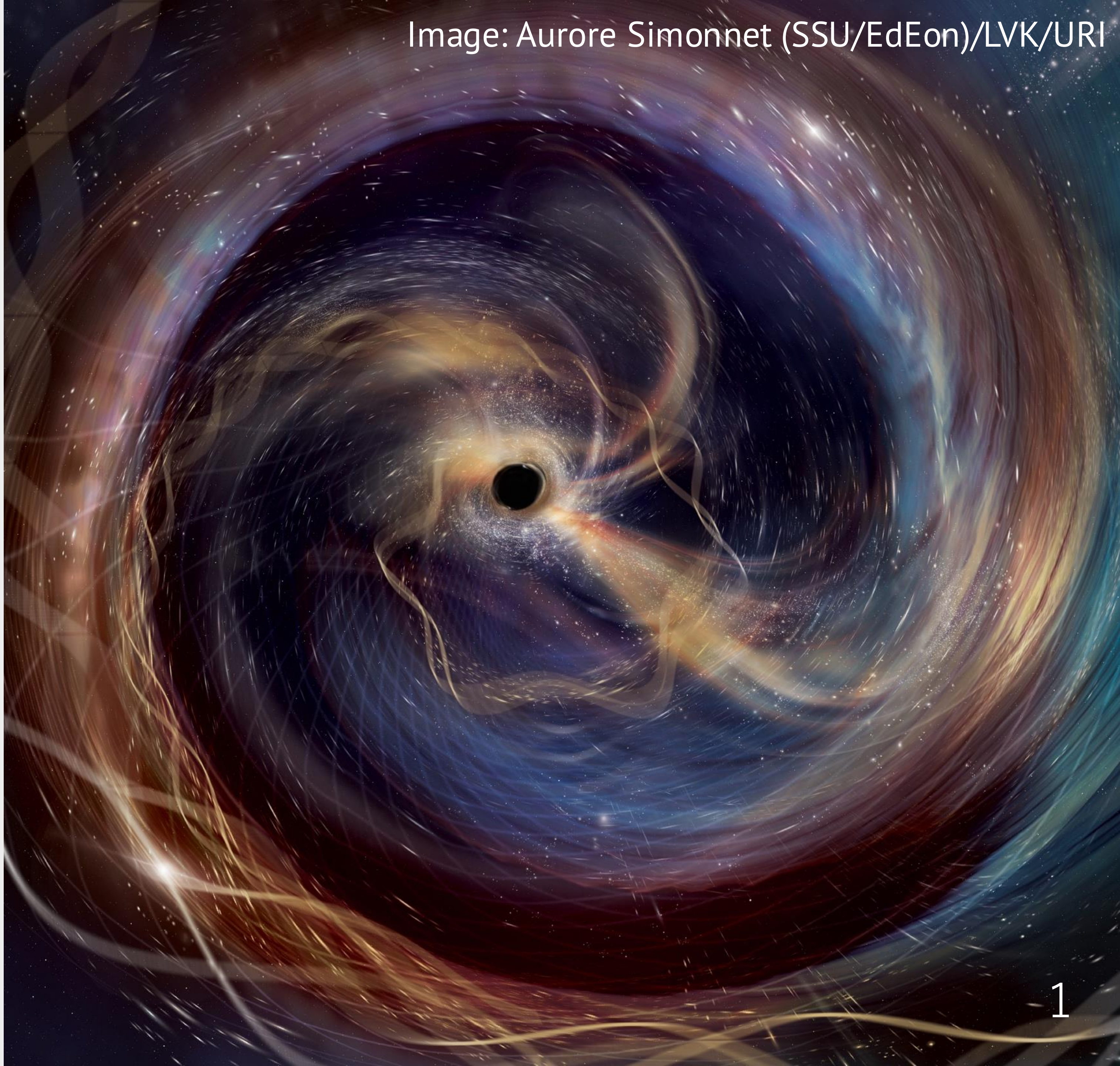


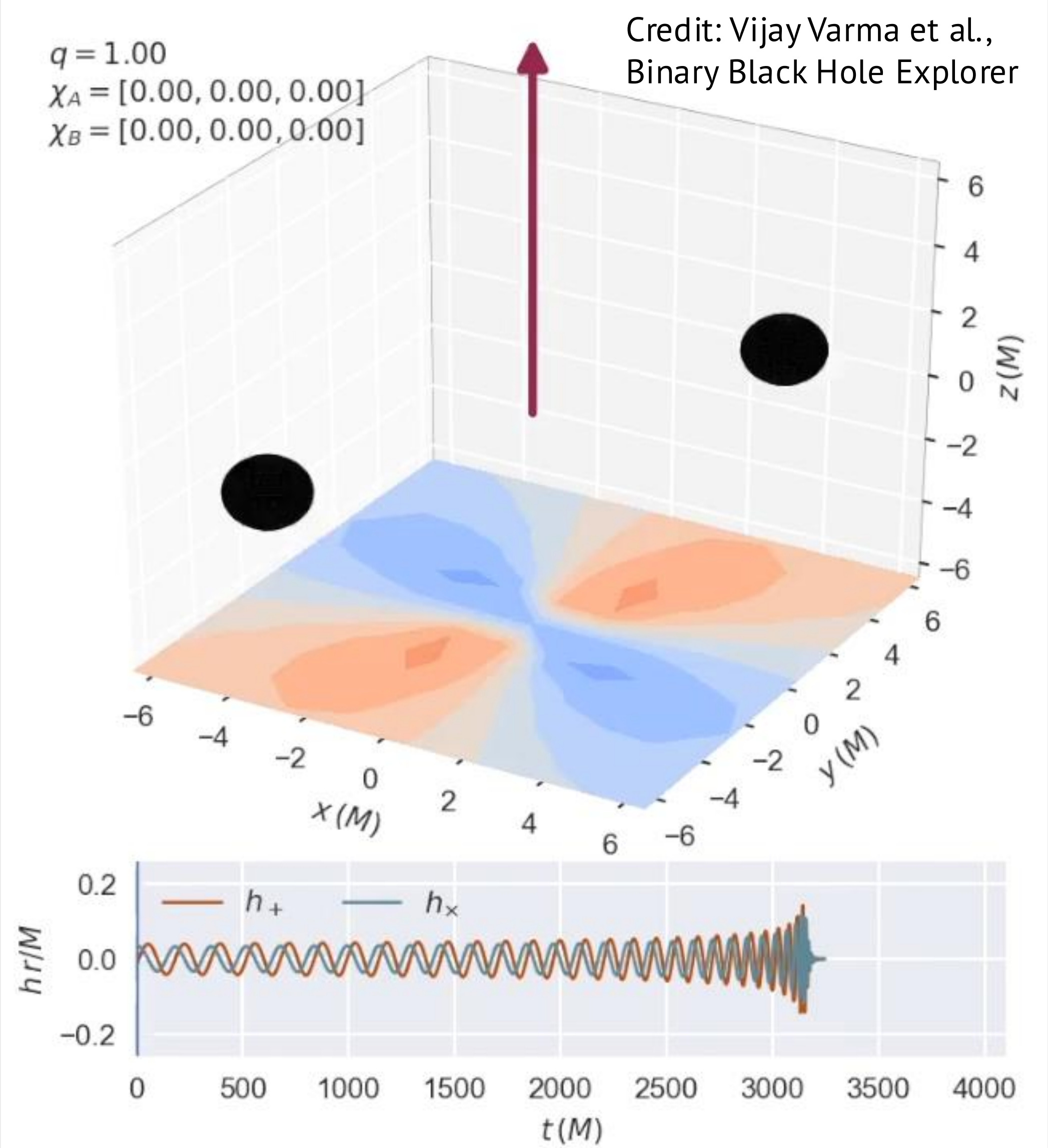
Image: Aurore Simonnet (SSU/EdEon)/LVK/URI

Gravitational Waves (in a single slide)

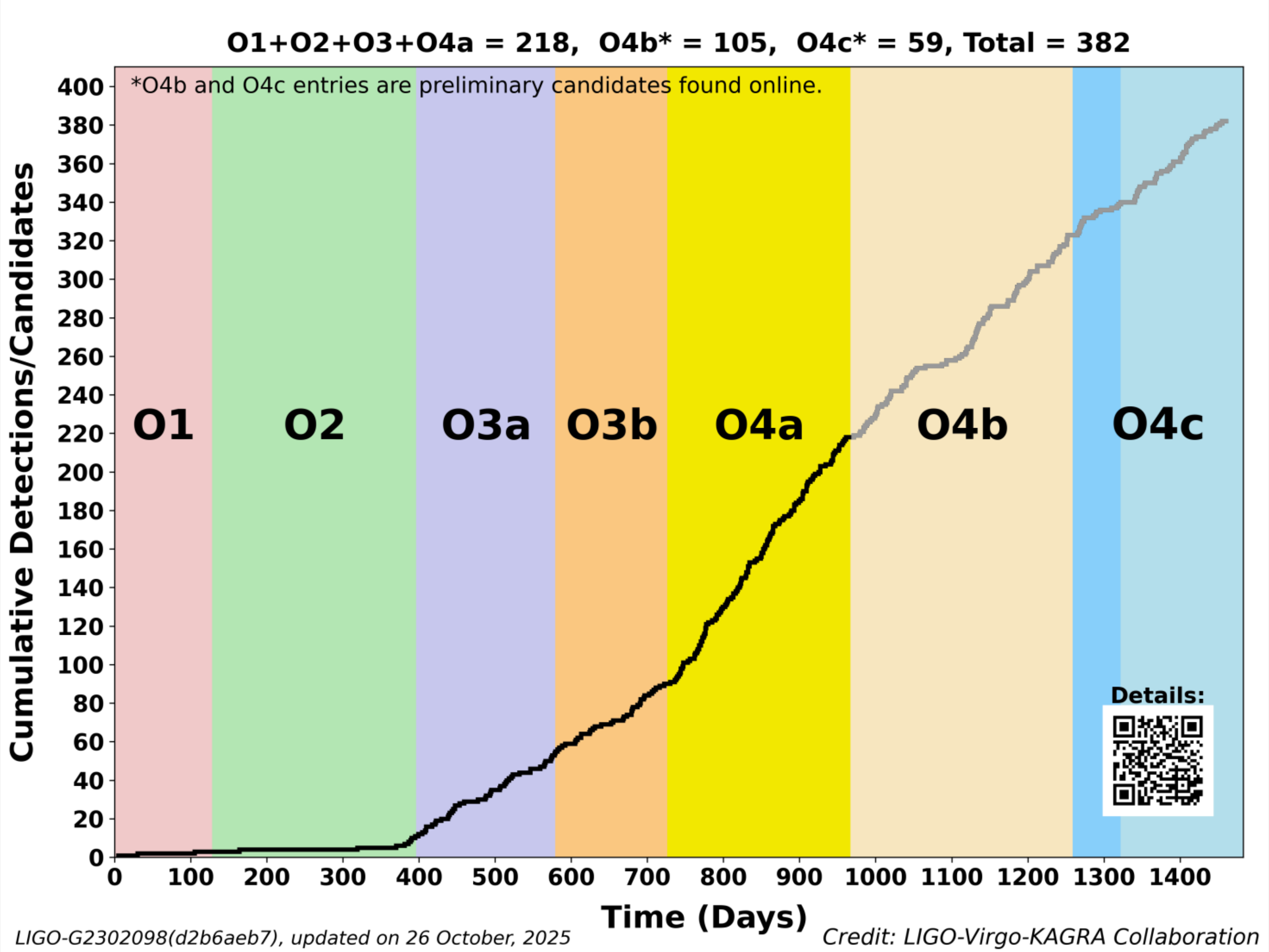
- **Primary (and so far only confirmed) source:** Compact Binary Coalescence (CBC)

- **Three CBC categories**
  - Binary Black Hole (BBH)
  - Neutron Star–Black Hole (NSBH)
  - Binary Neutron Star (BNS)

- **Four observing runs (O1, O2, O3, O4)** by **LIGO-Virgo-KAGRA** detector network
  - 90 CBC detections from O1–O3
  - O4 is ongoing and will conclude today.
  - LIGO's best BNS range: 180Mpc



O4 Alerts



Detection rate~1/(a few days)

- Mostly BBHs
- Several NSBH candidates
  - Recent candidates: S250206dm, S241109bn
- No conclusive BNSs

Several well-localized BBHs

- S250830bp (3.7 deg^2 at 90%)
- S240615dg (5 deg^2)
- S250119cv (9 deg^2)

O4a Data Release

LIGO-Virgo-KAGRA, arXiv: 2508.18082.

GWTC-4.0: Updating the Gravitational-Wave Transient Catalog with Observations from the First Part of the Fourth LIGO-Virgo-KAGRA Observing Run

THE LIGO SCIENTIFIC COLLABORATION, THE VIRGO COLLABORATION, AND THE KAGRA COLLABORATION

(Compiled: August 26, 2025)

ABSTRACT

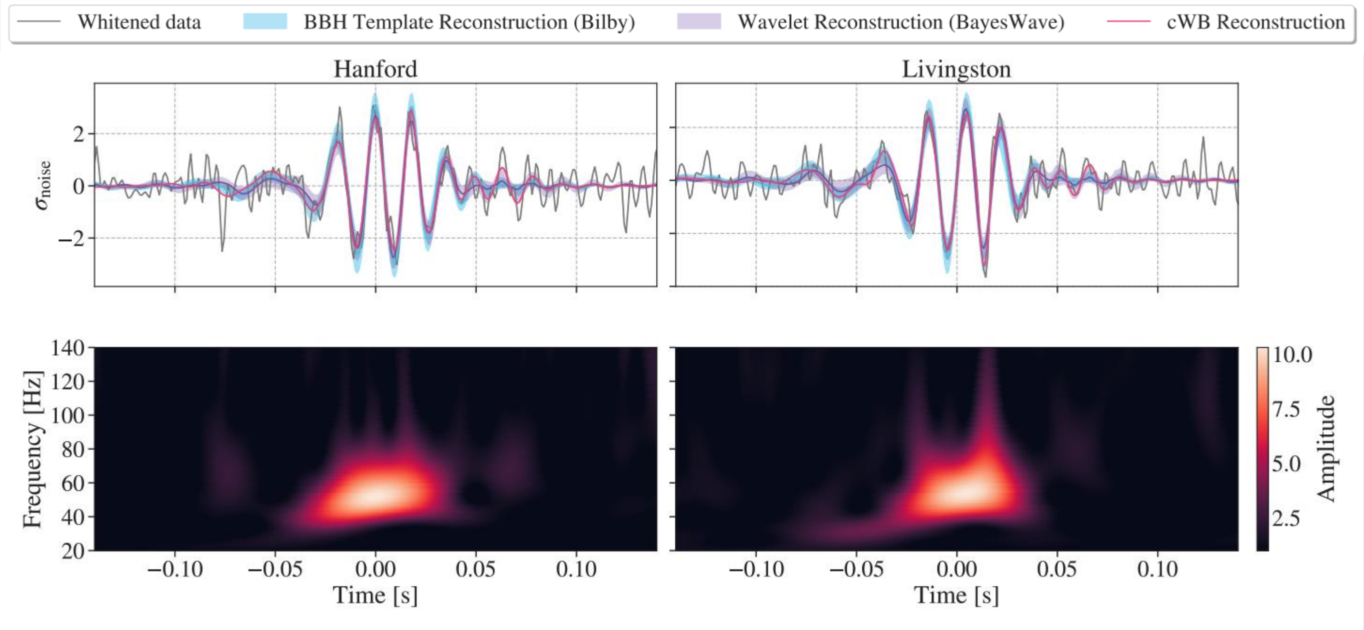
Version 4.0 of the Gravitational-Wave Transient Catalog (GWTC-4.0) adds new candidates detected by the LIGO, Virgo, and KAGRA observatories through the first part of the fourth observing run (O4a: 2023 May 24 15:00:00 to 2024 January 16 16:00:00 UTC) and a preceding engineering run. In these new data, we find 128 compact binary coalescence candidates that are identified by at least one of our search algorithms with a probability of astrophysical origin $p_{\rm astro} \geq 0.5$ and that are not vetoed during event validation. We also provide detailed source property measurements for 86 of these that have a false alarm rate $< 1\,{\rm yr}^{-1}$. Based on the inferred component masses, these candidates are consistent with signals from binary black holes and neutron star–black hole binaries (GW230518_125908 and GW230529_181500). Median inferred component masses of binary black holes in the catalog now range from $5.79\,M_\odot$ (GW230627_015337) to $137\,M_\odot$ (GW231123_135430), while GW231123_135430 was probably produced by the most massive binary observed in the catalog. For the first time we have discovered binary black hole signals with network signal-to-noise ratio exceeding 30, GW230814_230901 and GW231226_101520, enabling high-fidelity studies of the waveforms and astrophysical properties of these systems. Combined with the 90 candidates included in GWTC-3.0, the catalog now contains 218 candidates with $p_{\rm astro} \geq 0.5$ and not otherwise vetoed, more than doubling the size of the catalog and further opening our view of the gravitational-wave Universe.

128 new events from O4a (May 2023–January 2024)

+ a few exceptional events from O4b, c

LIGO-Virgo-KAGRA, PRL **135**, 111403 (2025),
LIGO-Virgo-KAGRA, ApJL **993**, L21 (2025).

GW231123: BBH with Total Mass 190–265$M_\odot$



Credit: LIGO-Virgo-KAGRA, ApJL **993** 1, L25 (2025).

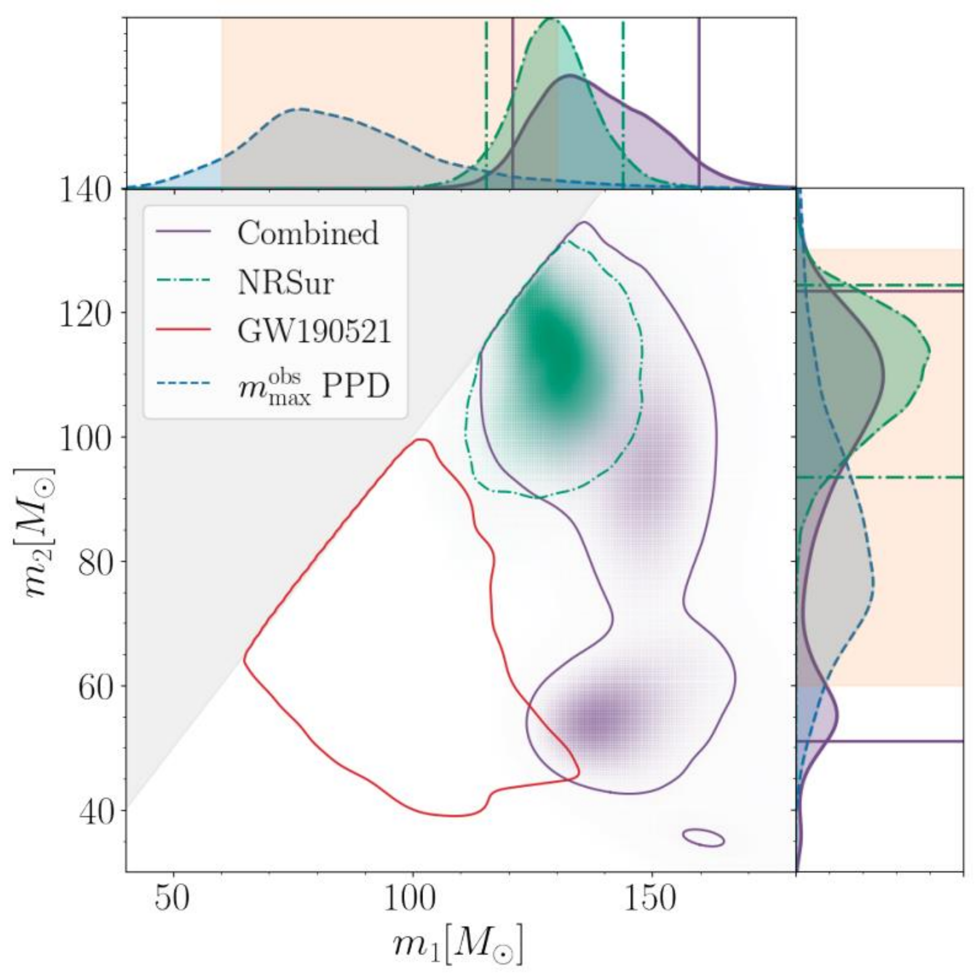
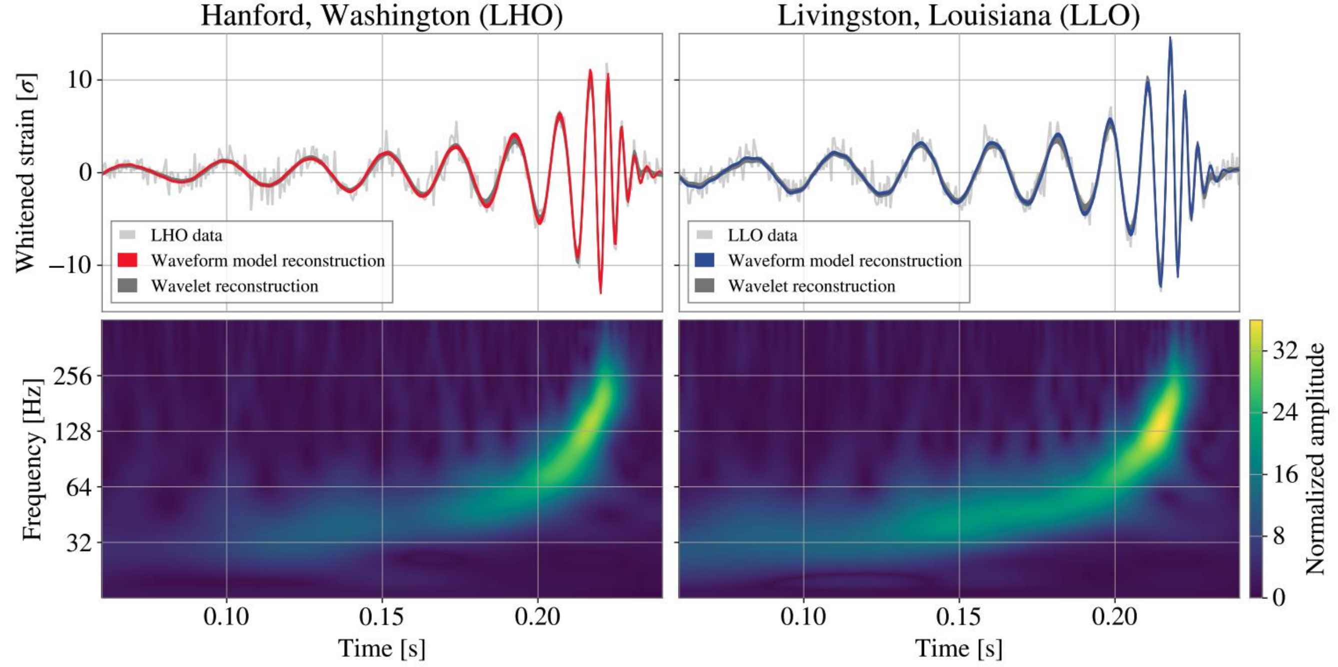


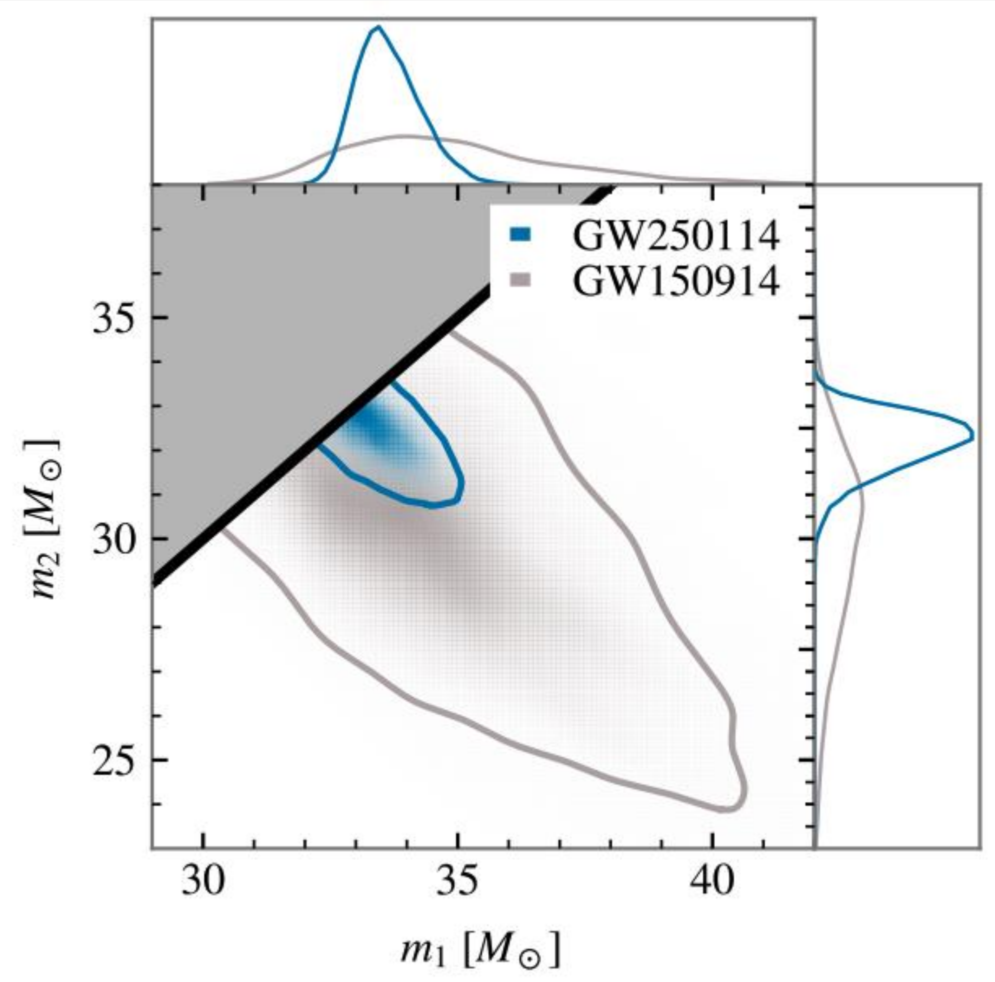
Figure: Inferred masses of GW231123

- The most massive BBH observed so far: $\boldsymbol{m_1 = 137^{+22}_{-17} M_\odot}$, $\boldsymbol{m_2 = 103^{+20}_{-52} M_\odot}$.
- The masses may be in the pair-instability mass gap (60–130$M_\odot$).
- Both BHs exhibit high spins: $\chi_1 = 0.90^{+0.10}_{-0.24}$, $\chi_2 = 0.80^{+0.20}_{-0.51}$.

GW250114: Loud BBH with SNR~80

Credit: LIGO-Virgo-KAGRA, PRL **135**, 111403 (2025).



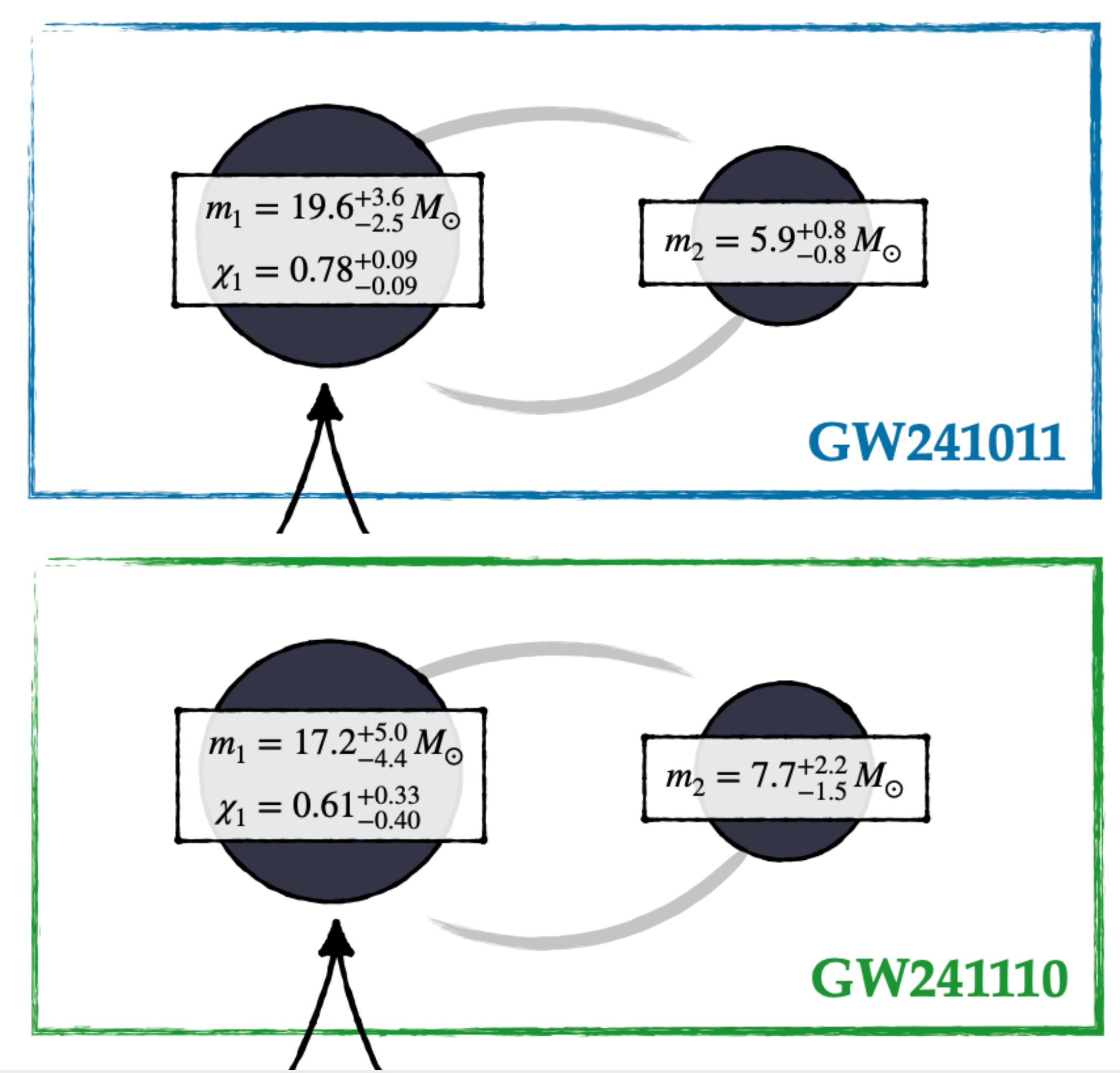


- A loud BBH with signal-to-noise ratio~80.
- Typical BBH:
  $m_1 = 33.6^{+1.2}_{-0.8} M_\odot, m_2 = 32.2^{+0.8}_{-1.3} M_\odot, \chi_{1,2} \leq 0.26.$
- Precise tests of Hawking's area law and the Kerr nature of a remnant black hole

Figure: Inferred masses of GW250114

GW241011 and GW241110: Possible Hierarchical Mergers

Credit: LIGO-Virgo-KAGRA, ApJL **993**, L21 (2025).



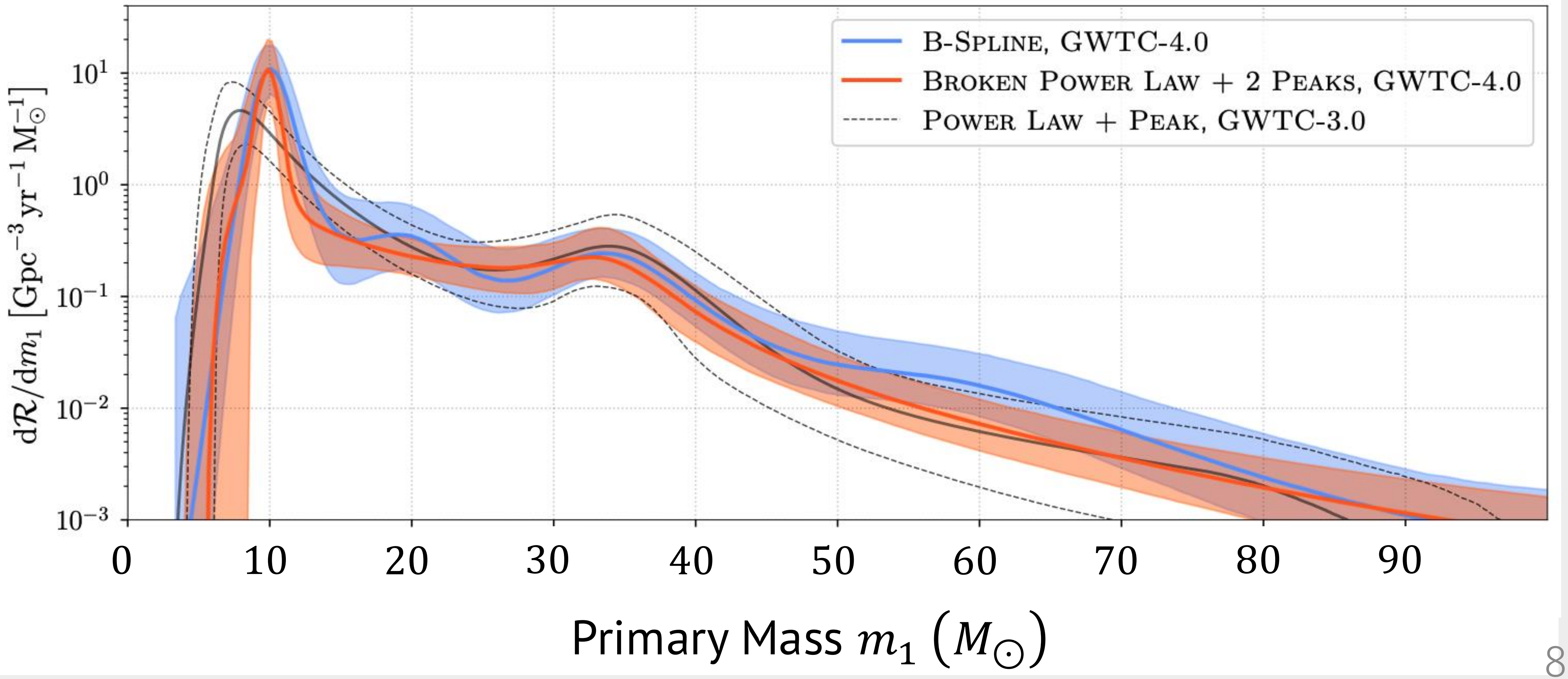
- Unequal masses and high primary spins → Primary BH might be formed by another BBH merger.

- GW241011 is the third loudest event with SNR~ 36, exhibiting strong signatures of orbital precession and higher-order modes.

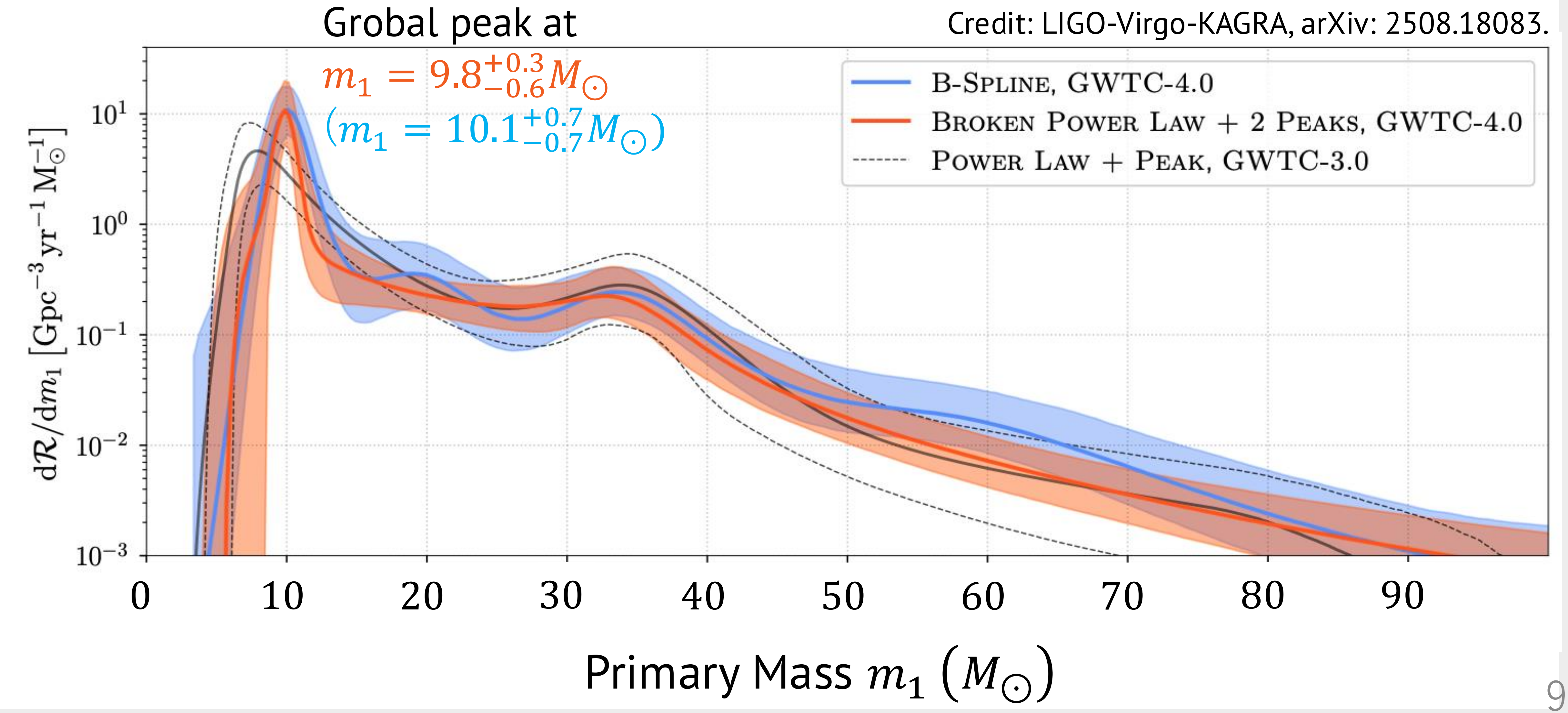
- GW241110's primary spin is likely significantly misaligned with orbital angular momentum, $\theta_1 > 90^\circ$ at 97.7%.

Population: Masses

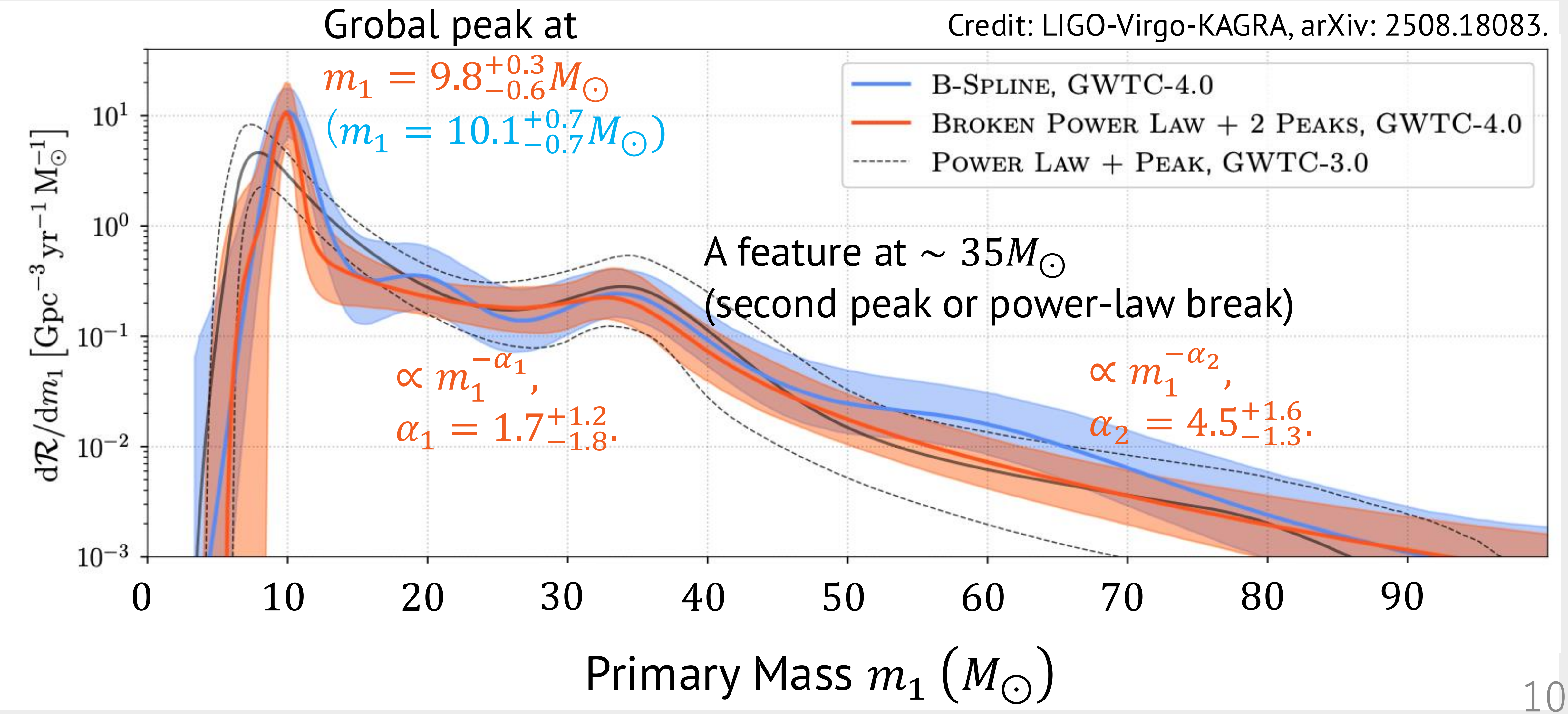
Credit: LIGO-Virgo-KAGRA, arXiv: 2508.18083.



Population: Masses

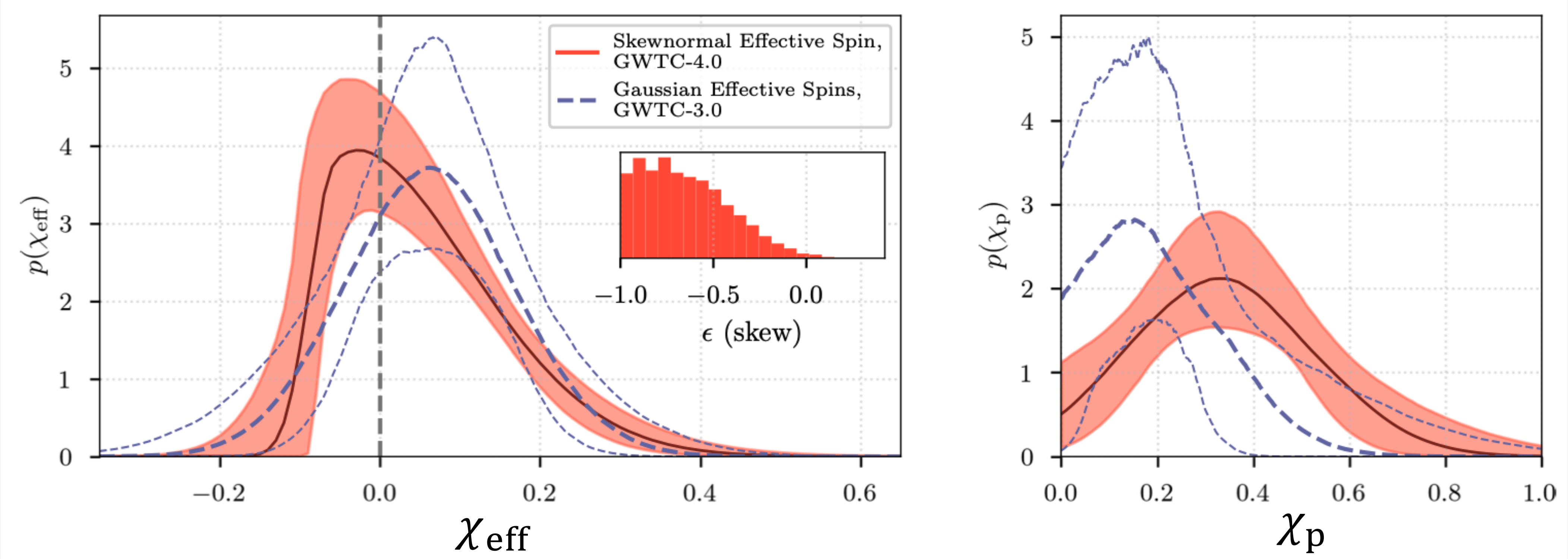


Population: Masses



Population: Spins

Credit: LIGO-Virgo-KAGRA, arXiv: 2508.18083.



- More support for spins aligned with orbital angular momentum *(See Kazuya's talk for more details).*
- Our analytic method was employed for accurate inference.

M. Iwaya, K. Kobayashi, *SM*, Kenta Hotokezaka, and Tomoya Kinugawa, PRD **111,** 103046 (2025).

Our Team

Tomoya Kinugawa (Shinshu U.)

Population of BBHs, GW Cosmology w/ **Kenta Hotokezaka (C02)**

Soichiro Morisaki

Hideyuki Tagoshi

Tathagata Ghosh

BH Ringdown, Sub-solar-mass BBH, Machine Learning

ICRR, UTokyo

Testing GR, CBC search

Kipp Cannon (RESCEU/UTokyo)

Atsushi Nishizawa (Hiroshima U.)

Our Projects and Publications (This Year)

- Statistical properties of BBHs *(See Kazuya's talk)*.

  M. Iwaya, K. Kobayashi, *SM*, Kenta Hotokezaka, and Tomoya Kinugawa, PRD **111,** 103046 (2025),
  T. Ghosh et al., ApJS 281, 11 (2025).

- Ringdown of a remnant blackhole *(See Motoki's talk)*.

  SM, H. Motohashi, M. Suzuki, D. Watarai, arXiv: 2507.12376 (2025).

- Search for sub-solar-mass BBHs *(See Yasuhiro's poster)*.

  Y. Murakami, T. Ghosh, *SM*, arXiv: 2511.XXXXX (2025).

- Rapid parameter estimation using machine learning for O5 *(See Kazuki's poster)*.
- Tests of General Relativity with GWs

  H. Imafuku, H. Takeda, A. Nishizawa, D. Watarai, and K. Cannon, PRD **112**, 024028 (2025),
  D. Watarai, A. Nishizawa, H. Takeda, H. Imafuku, and K. Cannon, arXiv: 2509.17592 (2025).

- Search for ultralight bosonic dark matter with GW data.

  SM et al., arXiv: 2503.04484 (2025).

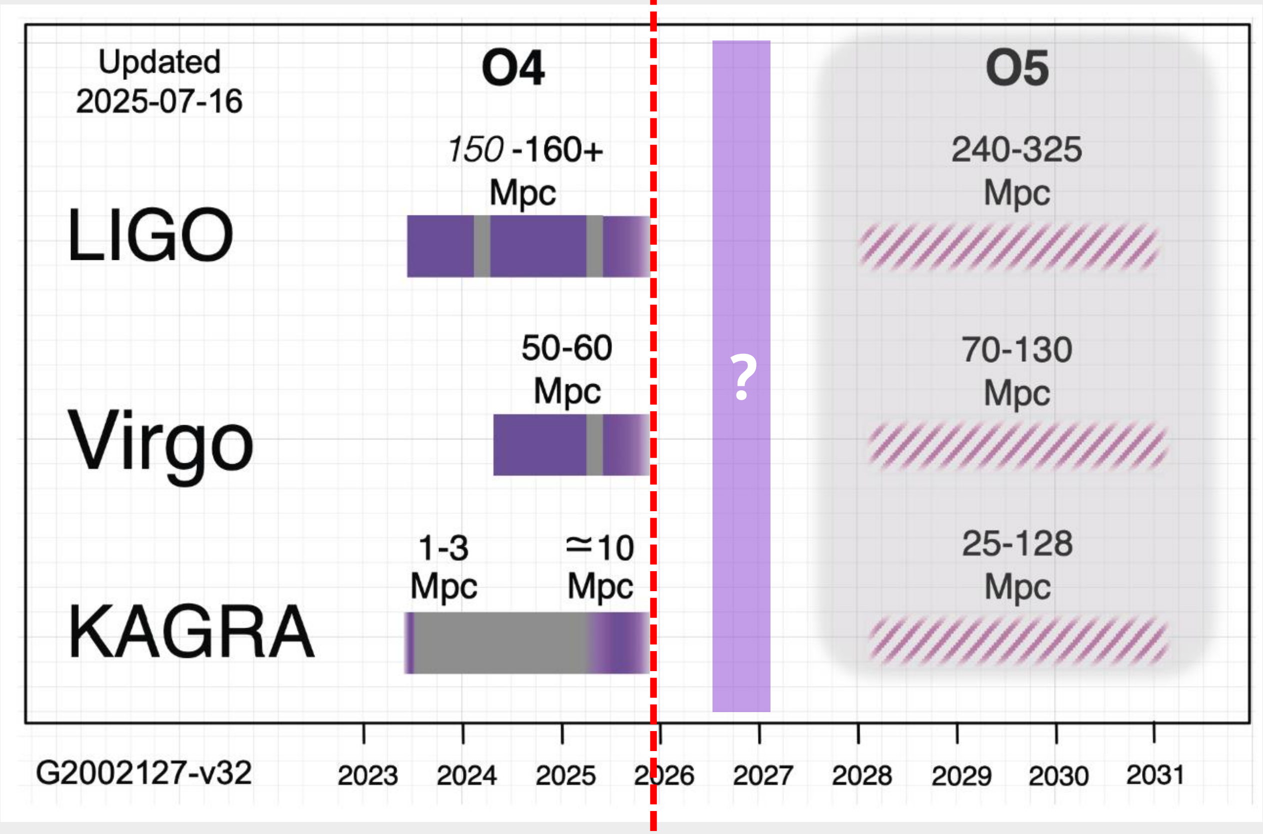
Future Observations

Credit: https://observing.docs.ligo.org/plan/

LIGO, VIRGO AND KAGRA OBSERVING RUN PLANS

(3 November 2025 update; next update 18 November 2025 or sooner)

The fourth observing run (O4) will conclude, as planned, on 18 November 2025. LIGO, Virgo, and KAGRA interferometers will then undergo a period of upgrades and commissioning. After recent assessments of upgrade phasing and discussions with funding agencies, we now expect to have a period of science observing in 2026-27. We currently envision a six month observing run to begin in the late summer/early fall of 2026, with detectors participating as available. We will update this page as the plans become firmer.



Now

Conclusion

- Several interesting events from O4!
  - GW231123: BBH with Total Mass $190-265 M_{\odot}$
  - GW250114: Loud BBH with SNR~80
  - GW241011 and GW241110: Possible Hierarchical Mergers

- More precise understanding of mass and spin distribution of BBHs.

- Our team actively works for maximizing the scientific outcomes from O4 data (Spin distribution of BBHs, tests of GR, sub-solar-mass BBHs, machine learning, etc.).

- Possible ~6-month observation run in 2026−2027.