

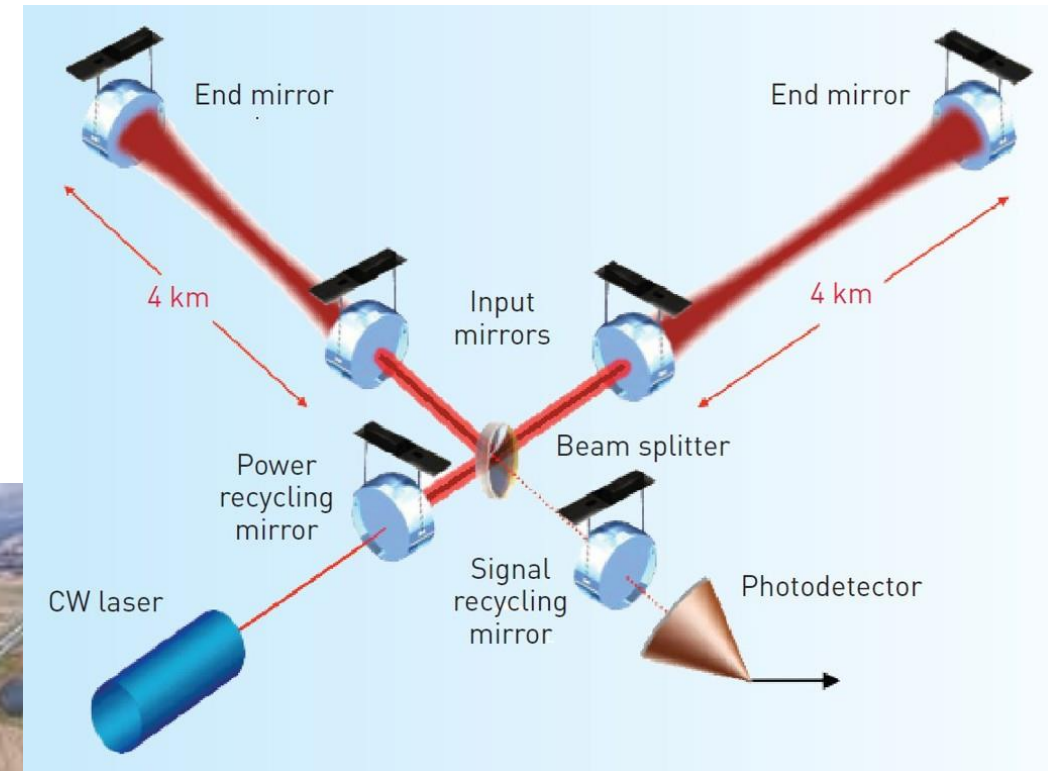
GWTC-5.0

Observations from the Second Part of the Fourth LIGO-Virgo-KAGRA Observing Run (O4b)

Jade Powell on behalf of the LIGO-Virgo-KAGRA Scientific
Collaborations



Gravitational Wave Observatories



Compact Binaries

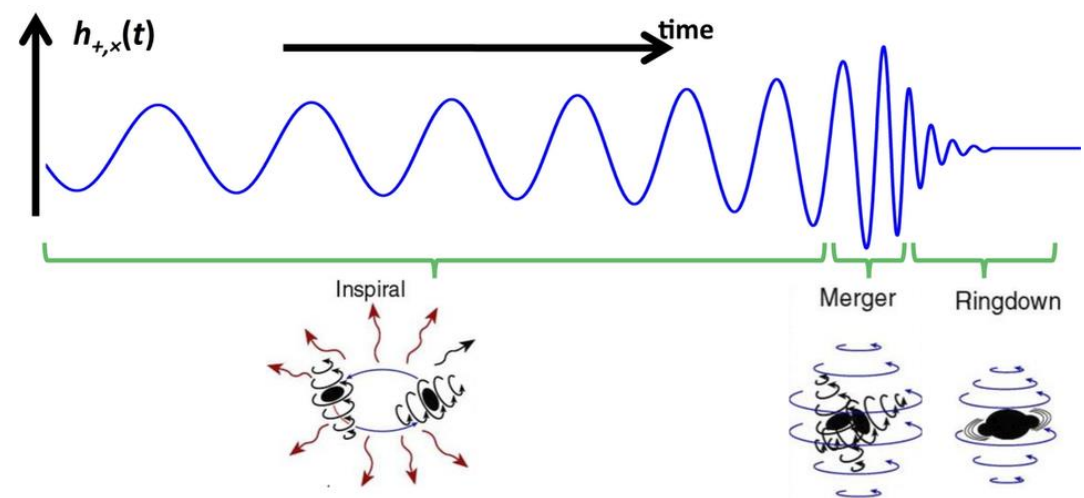


Image credit: M. Favata/SXS/K. Thorne

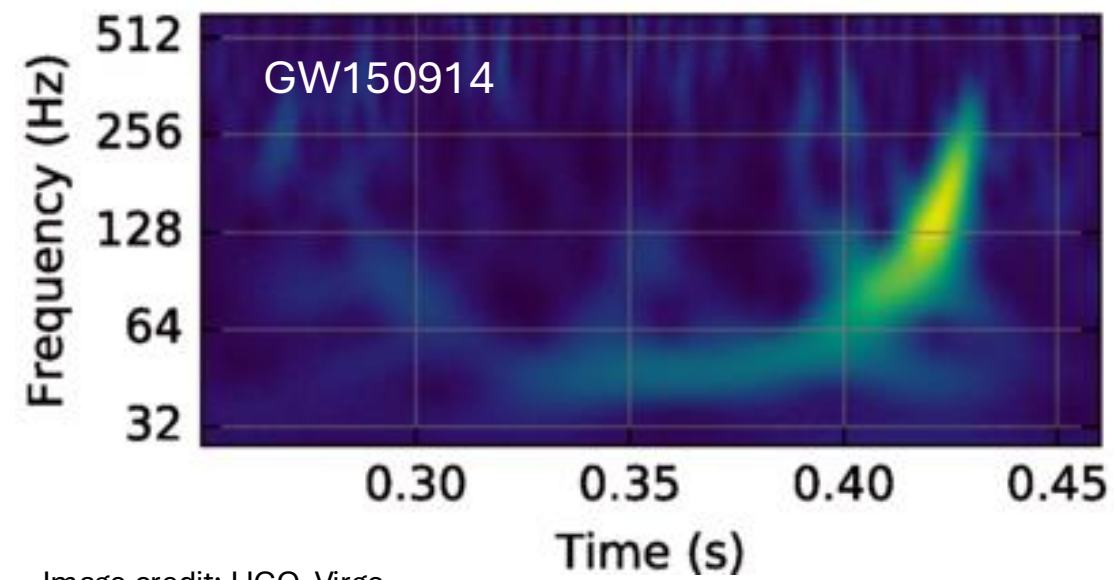
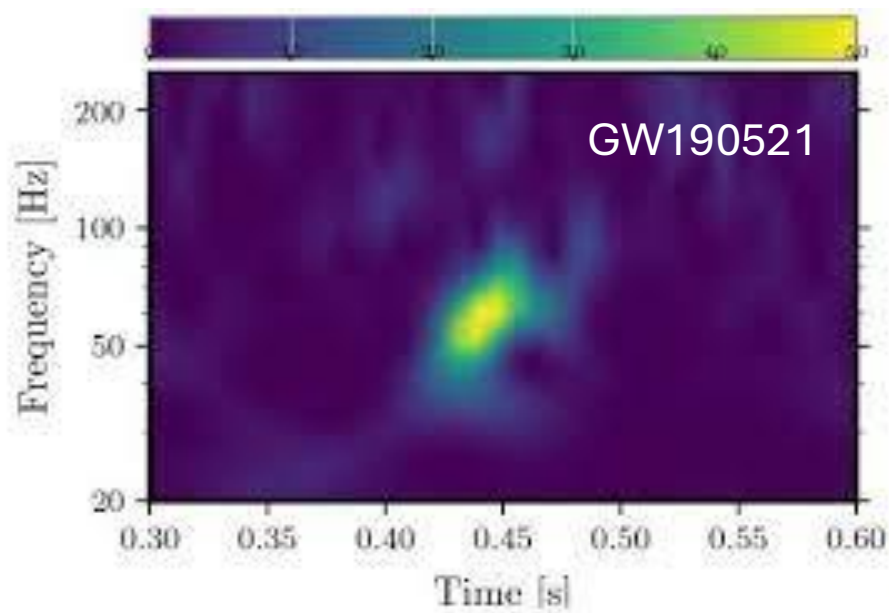
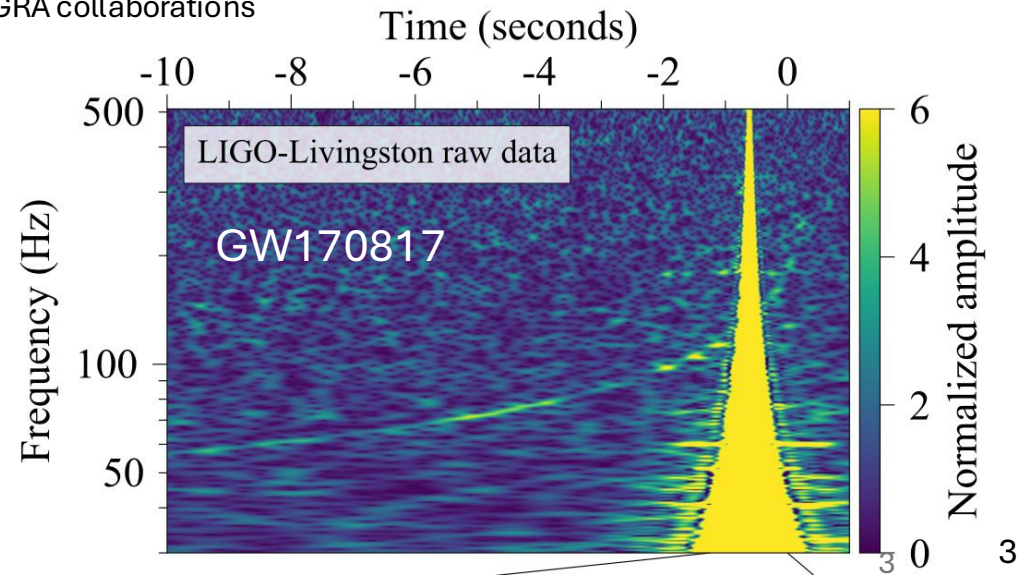
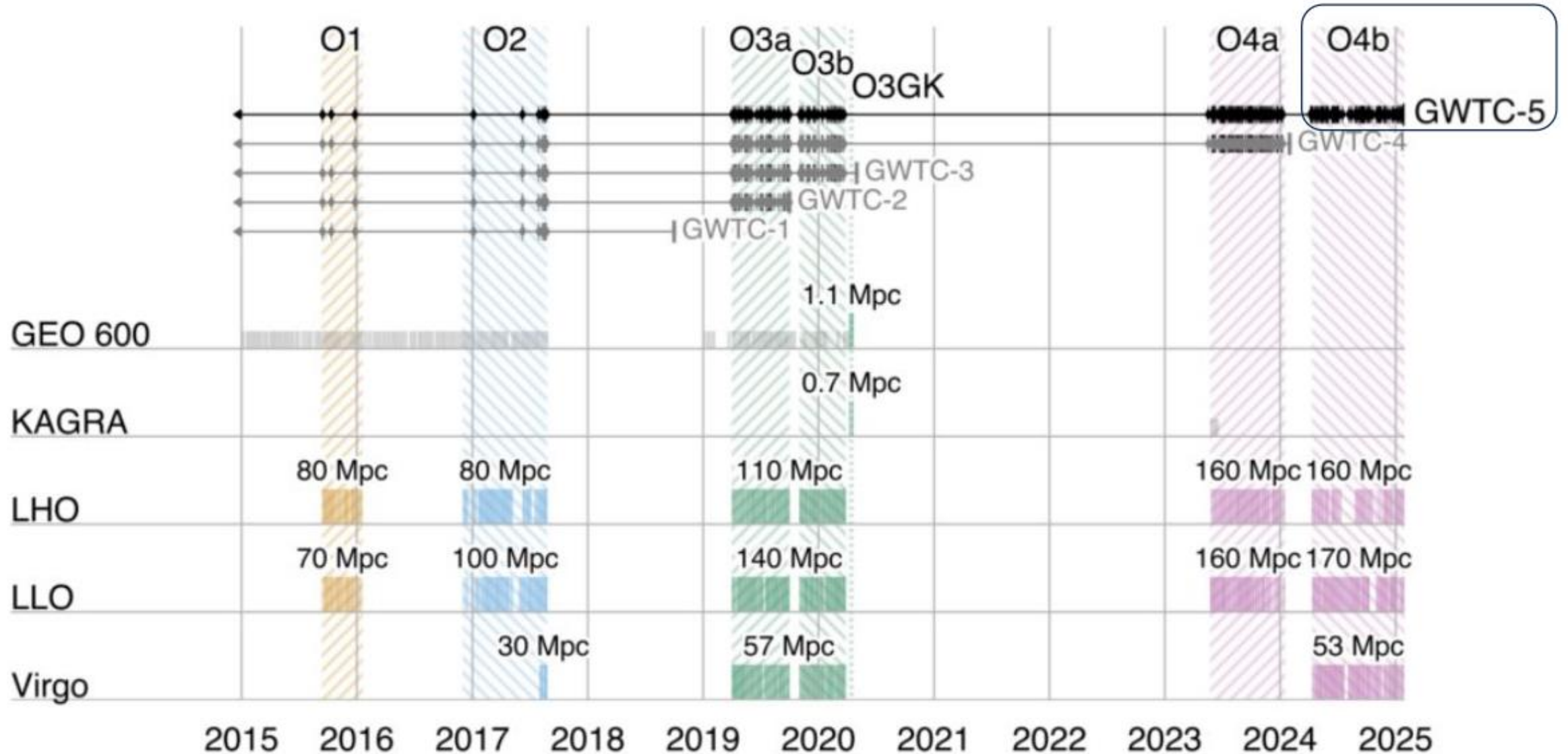


Image credit: LIGO, Virgo, KAGRA collaborations

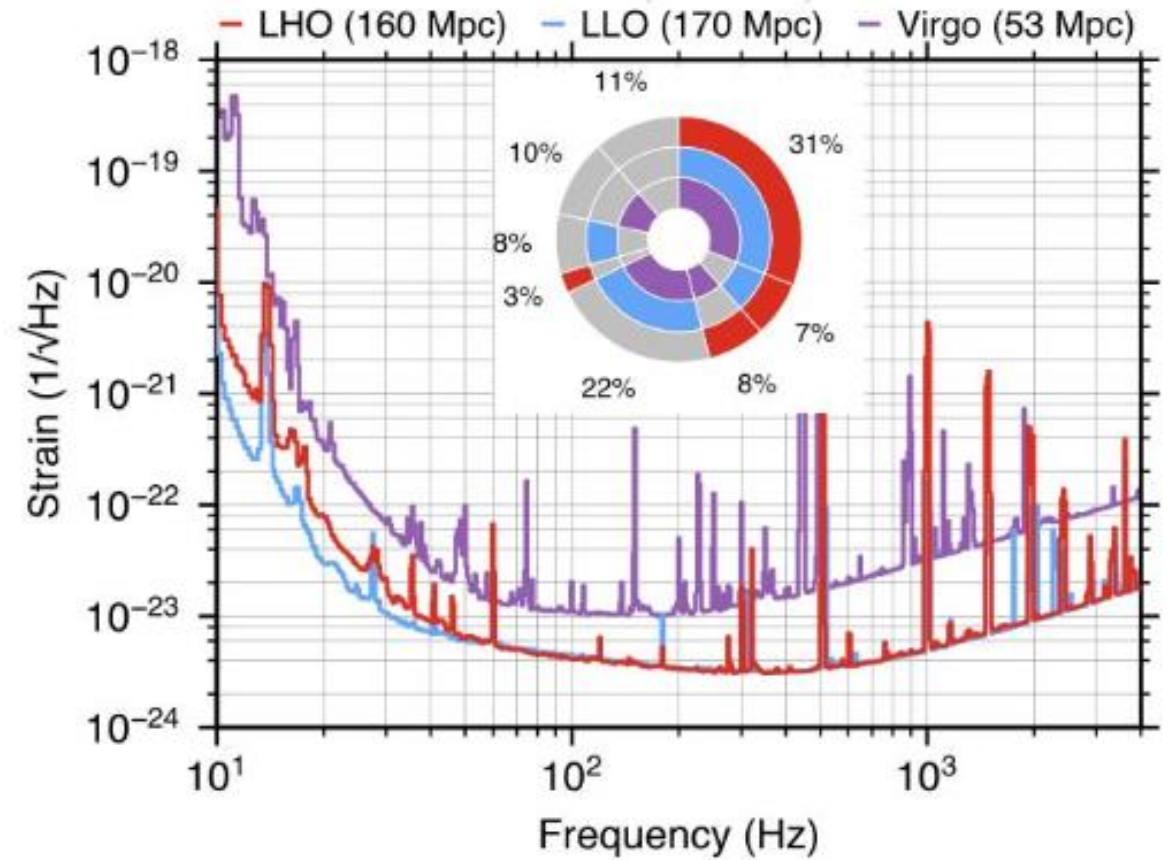
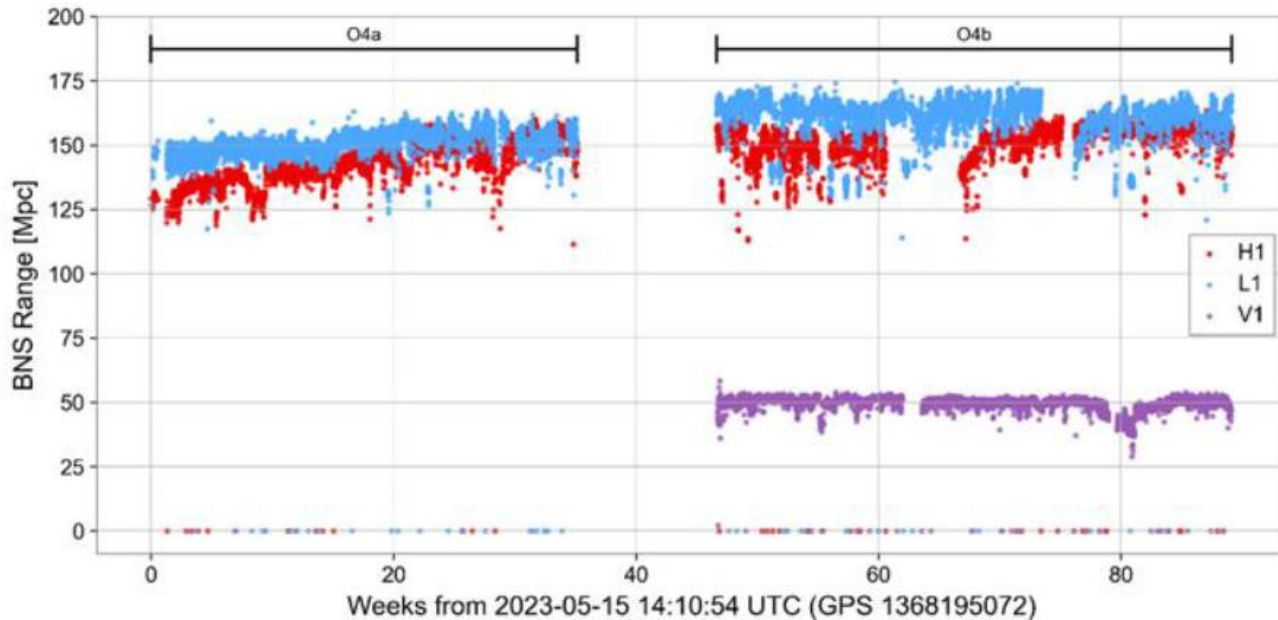


The GW Transient Catalogue (GWTC-5.0)



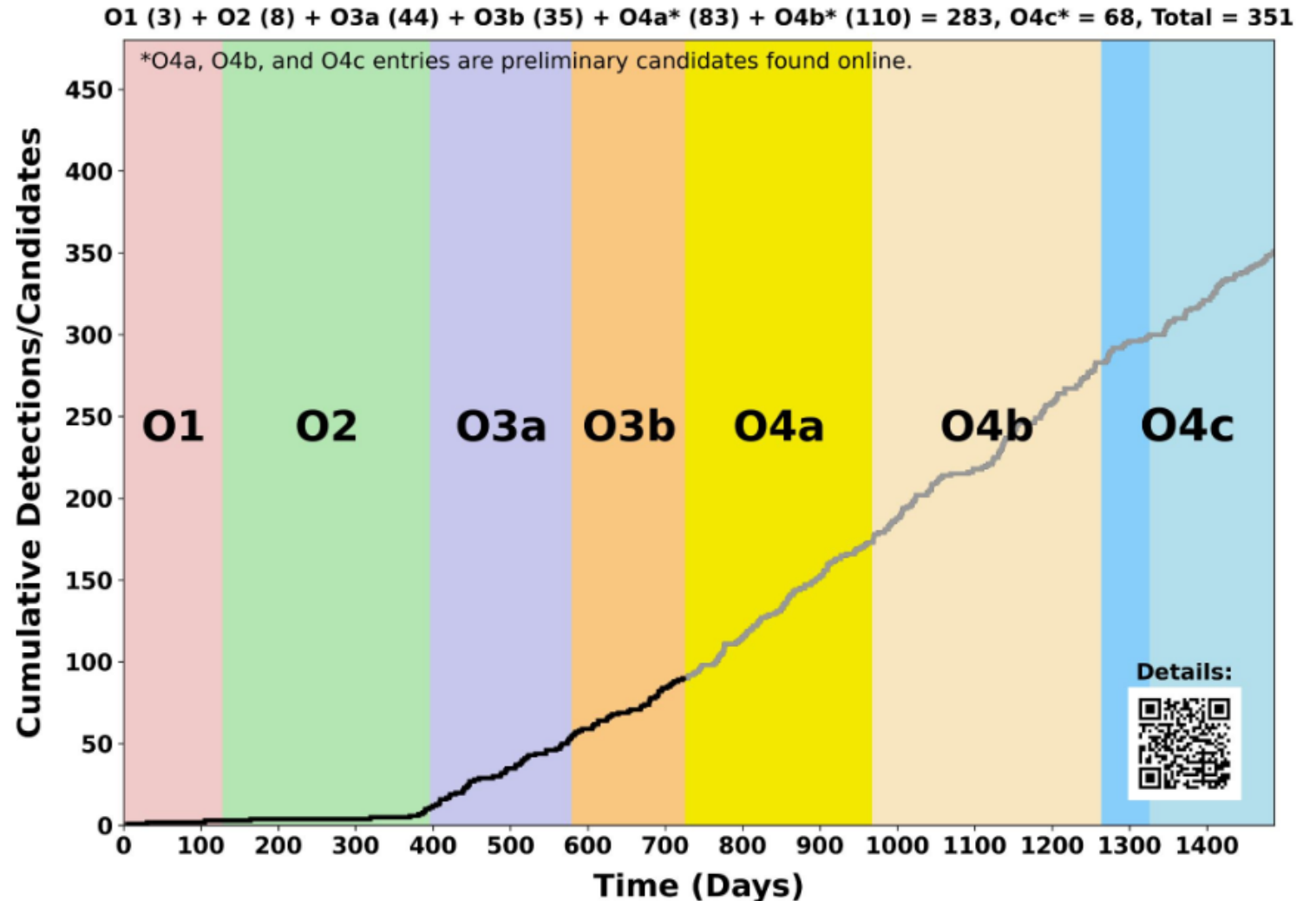
The O4b Observing Run

- April 10, 2024, to January 28, 2025.



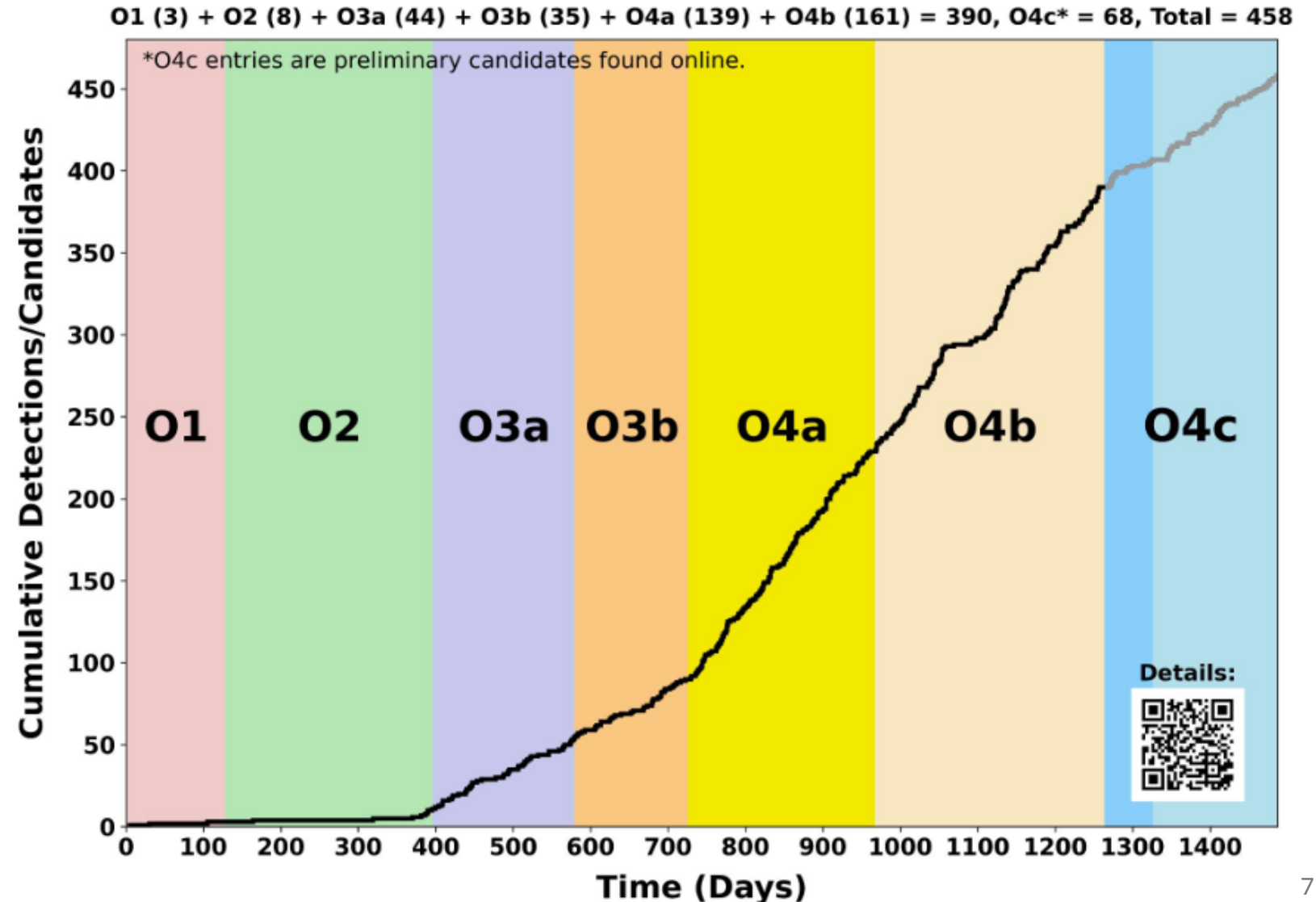
Online Search Events

- A number of GW searches run in low-latency.
- This enables us to get alerts out quickly to the astronomy community.
- <https://gracedb.ligo.org>



Offline Search Events

- More sensitive searches offline.
- Improved data quality?
- More accurate parameter estimation.
- O4b – 161 new events!

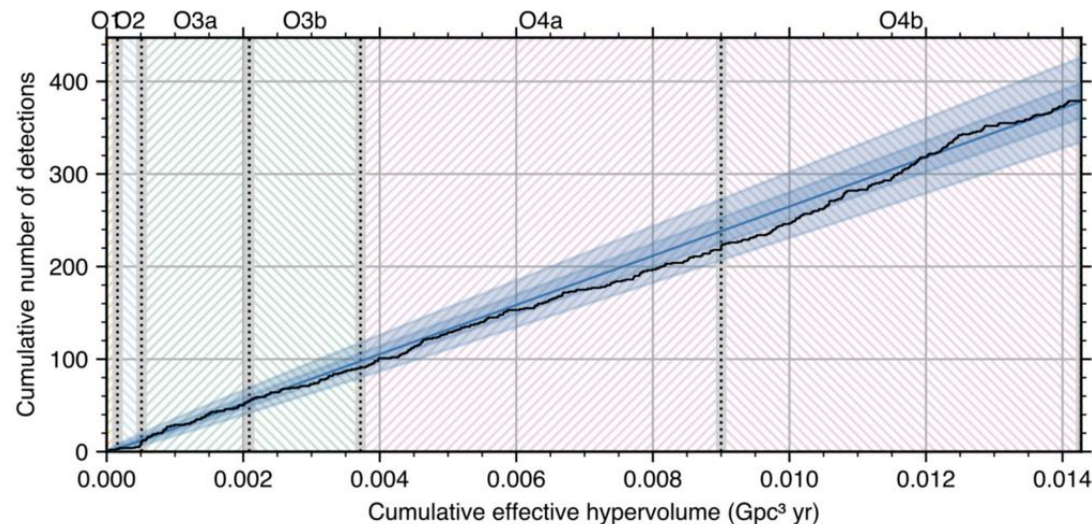


The GWTC Focus Issue

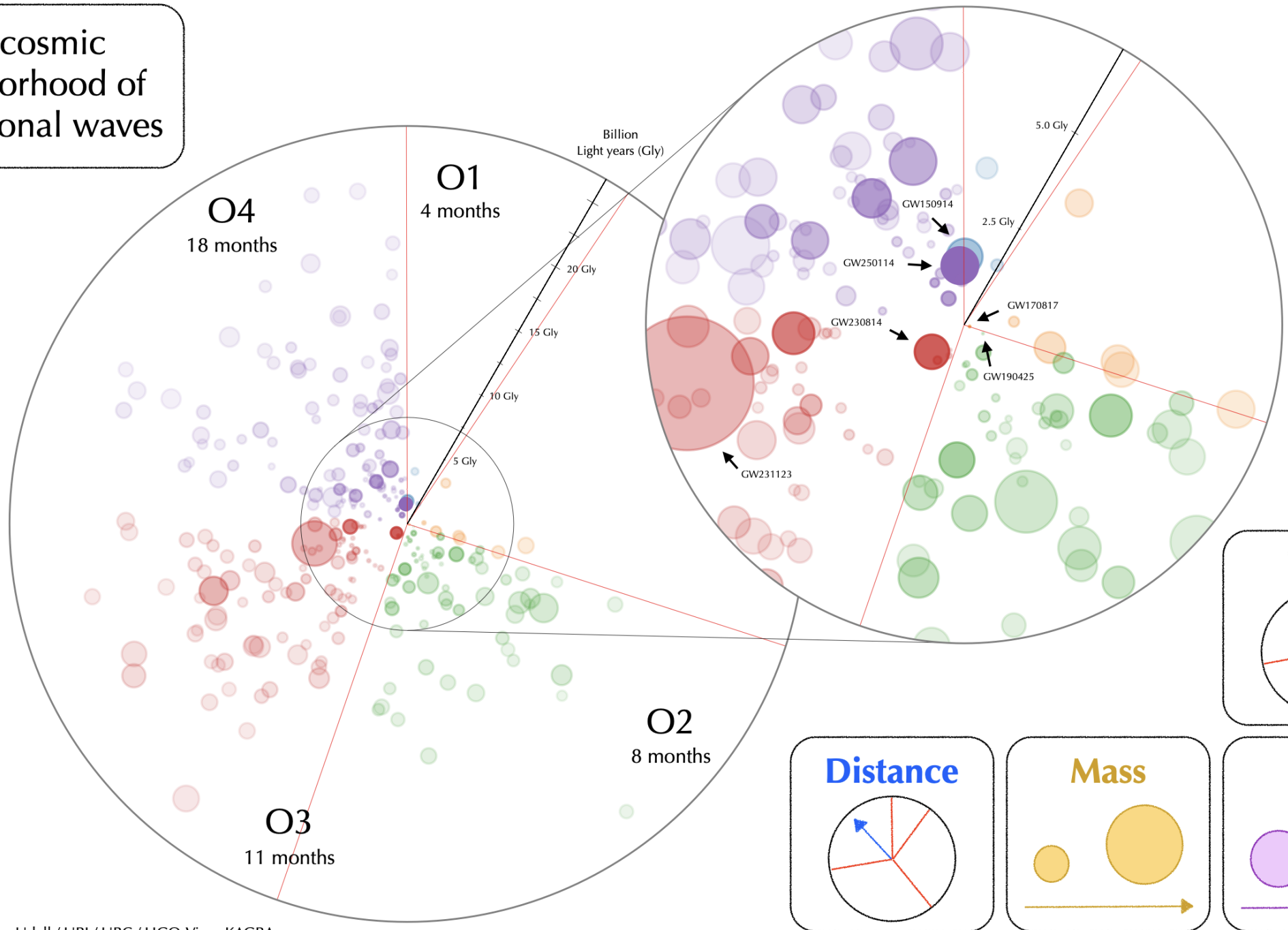
- GWTC is a cumulative catalog of observed gravitational wave events.
- The papers in the Focus Issue are companion papers that describe the methods, observations and science results.
 - GWTC-5.0: Introduction <https://arxiv.org/abs/2605.27223>
 - GWTC-5.0: Methods <https://arxiv.org/abs/2605.27224>
 - GWTC-5.0: Results <https://arxiv.org/abs/2605.27225>
 - GWTC-5.0: Populations <https://arxiv.org/abs/2605.27226>
 - GWTC-5.0: Cosmology <https://arxiv.org/abs/2605.27227>
 - O4b open data <https://arxiv.org/abs/2605.27090>

GWTC-5.0: Summary

- 161 new events.
- All new events are binary black holes.
- Parameter Estimation (masses, spins, etc.) provided for 104 of the new events.
- Total number of gravitational-wave events now 390.

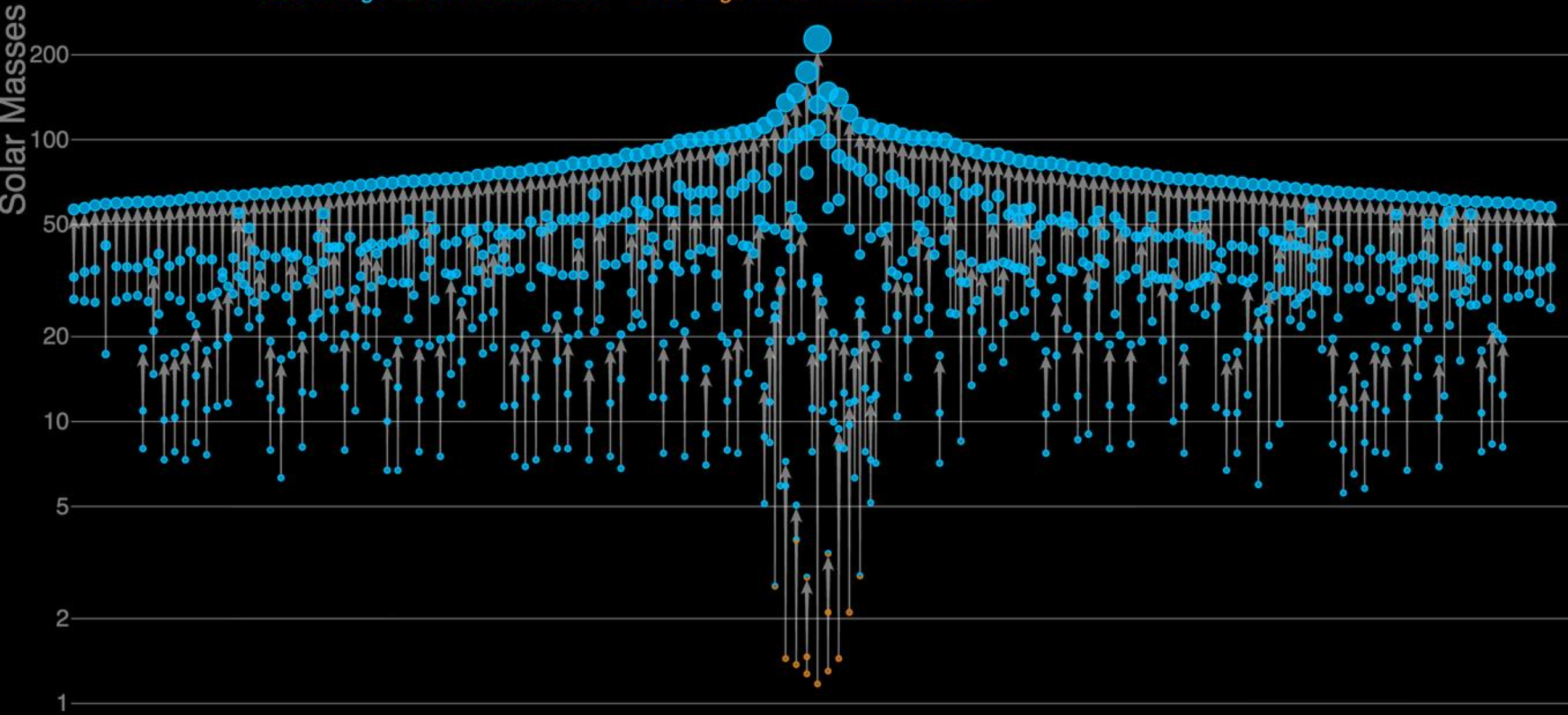


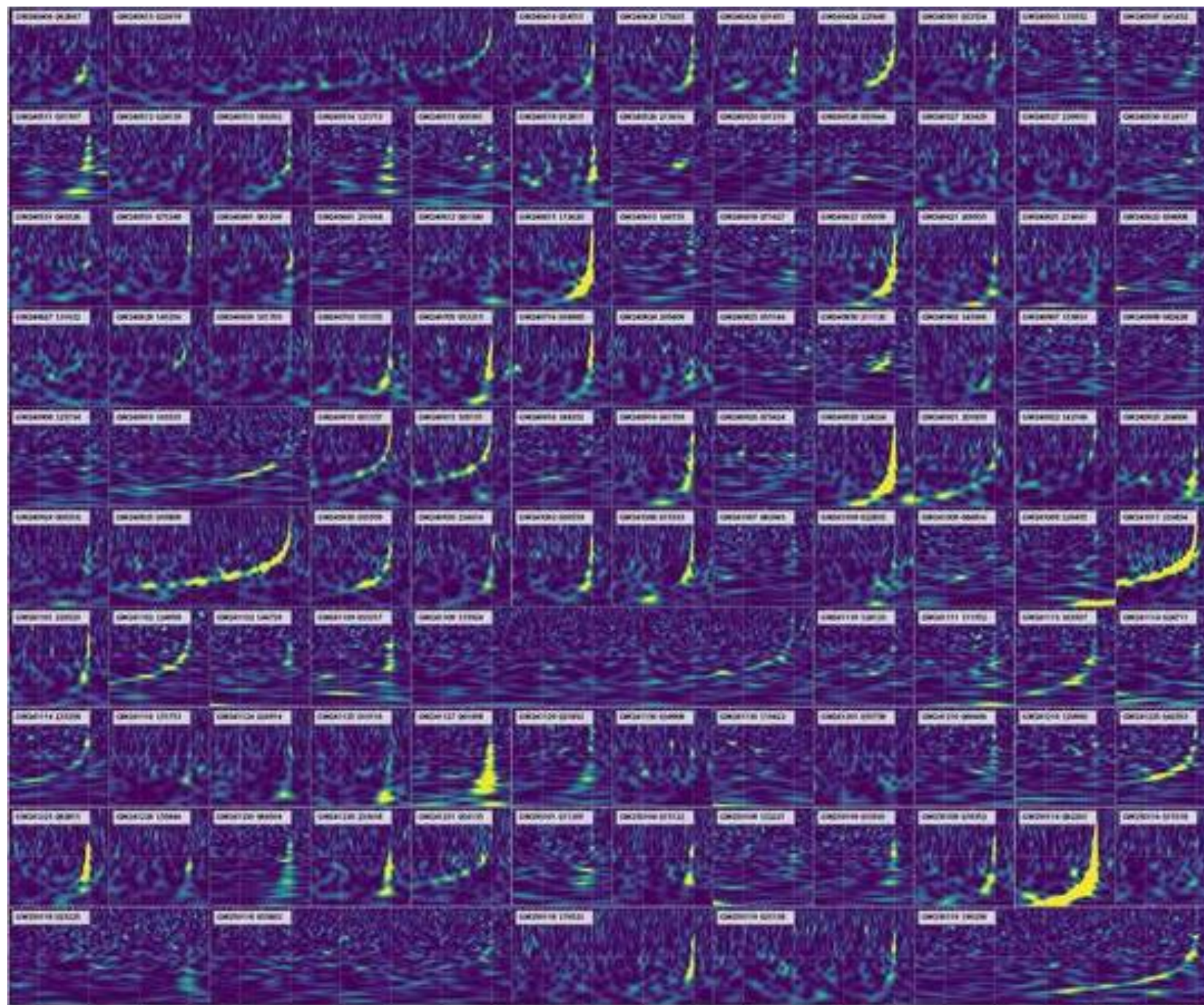
The cosmic neighborhood of gravitational waves



Masses in the Stellar Graveyard

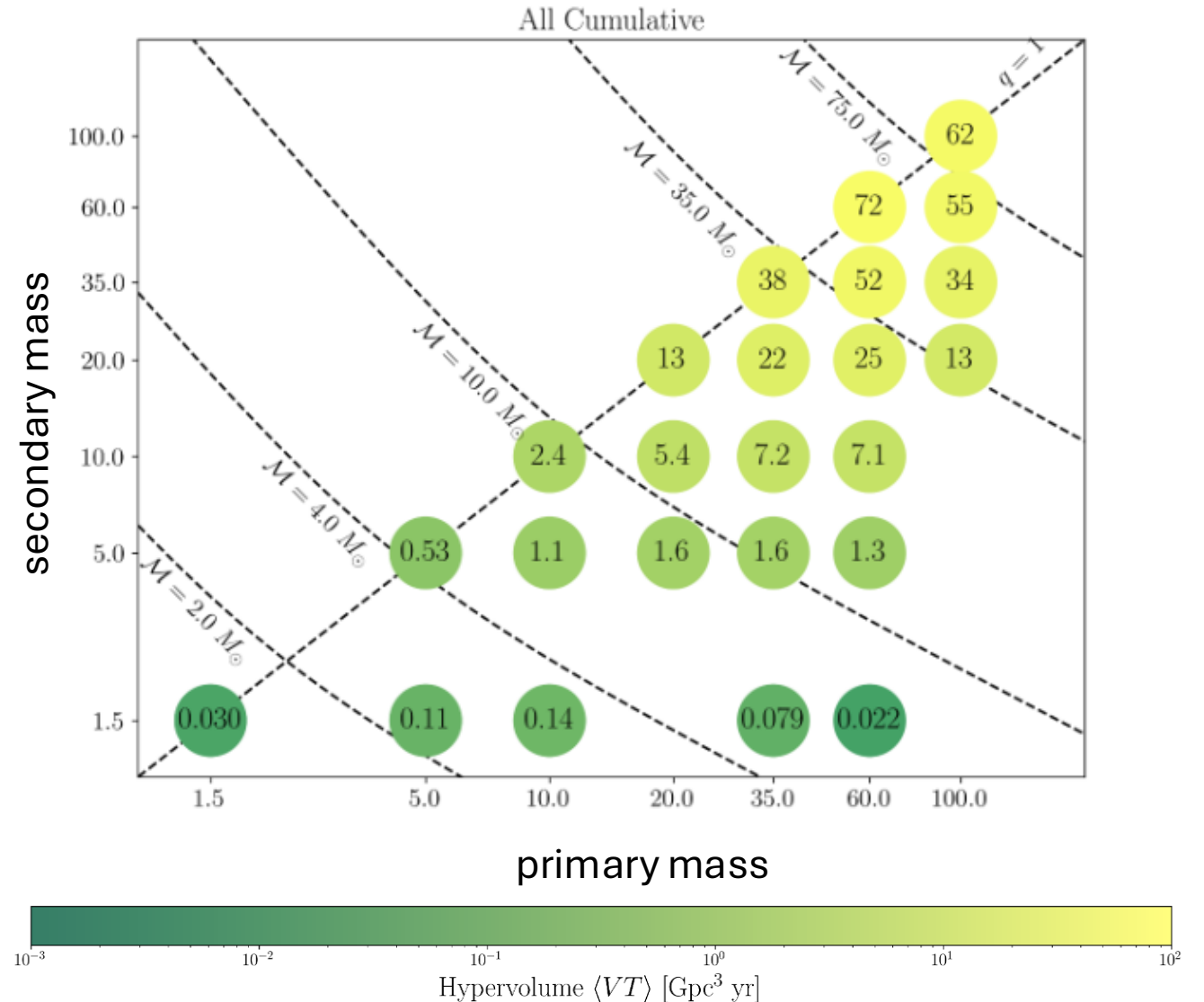
LIGO-Virgo-KAGRA Black Holes *LIGO-Virgo-KAGRA Neutron Stars*





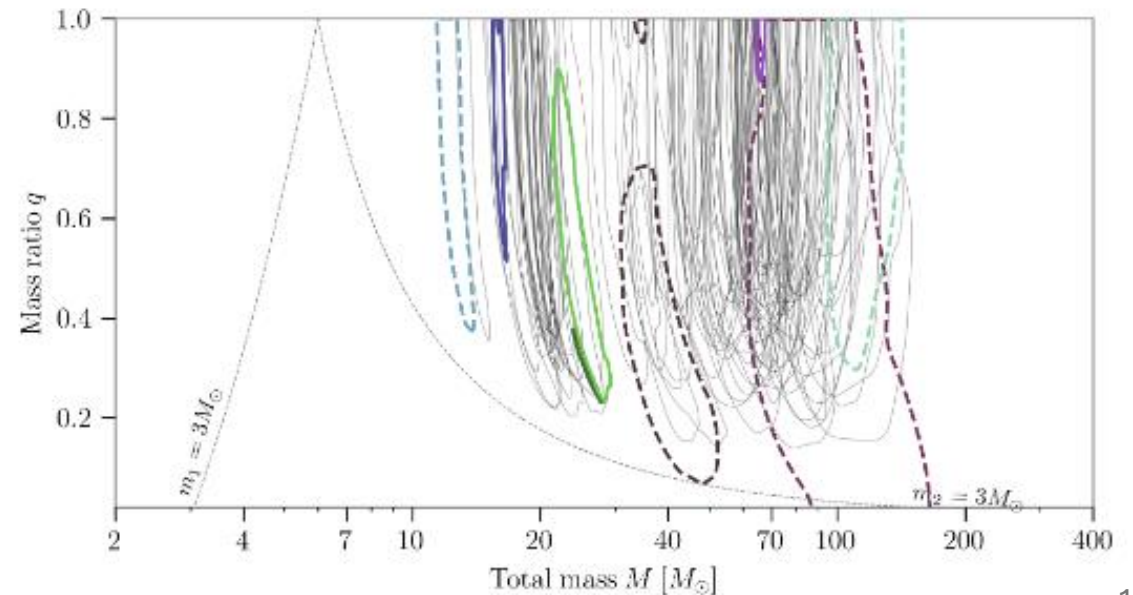
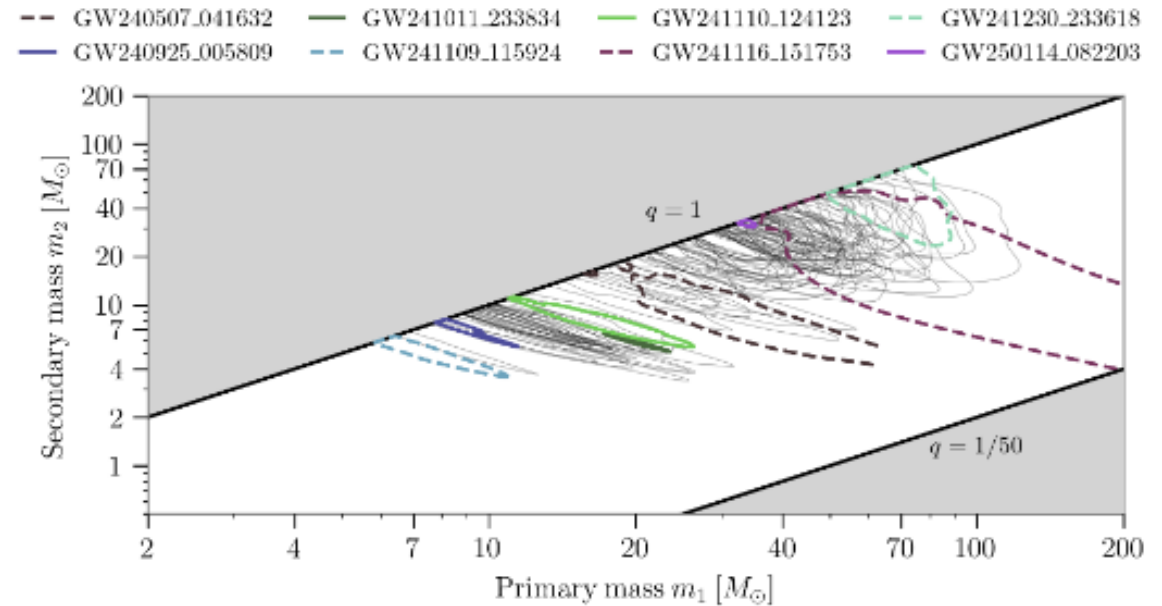
Search Sensitivity

- Injection studies were conducted to estimate the surveyed volume x time (VT) for each search pipeline for O4b.
- O4b's VT increased by ~20% compared to O4a's.
- O4a+O4b accounts for ~75% of the cumulative VT.



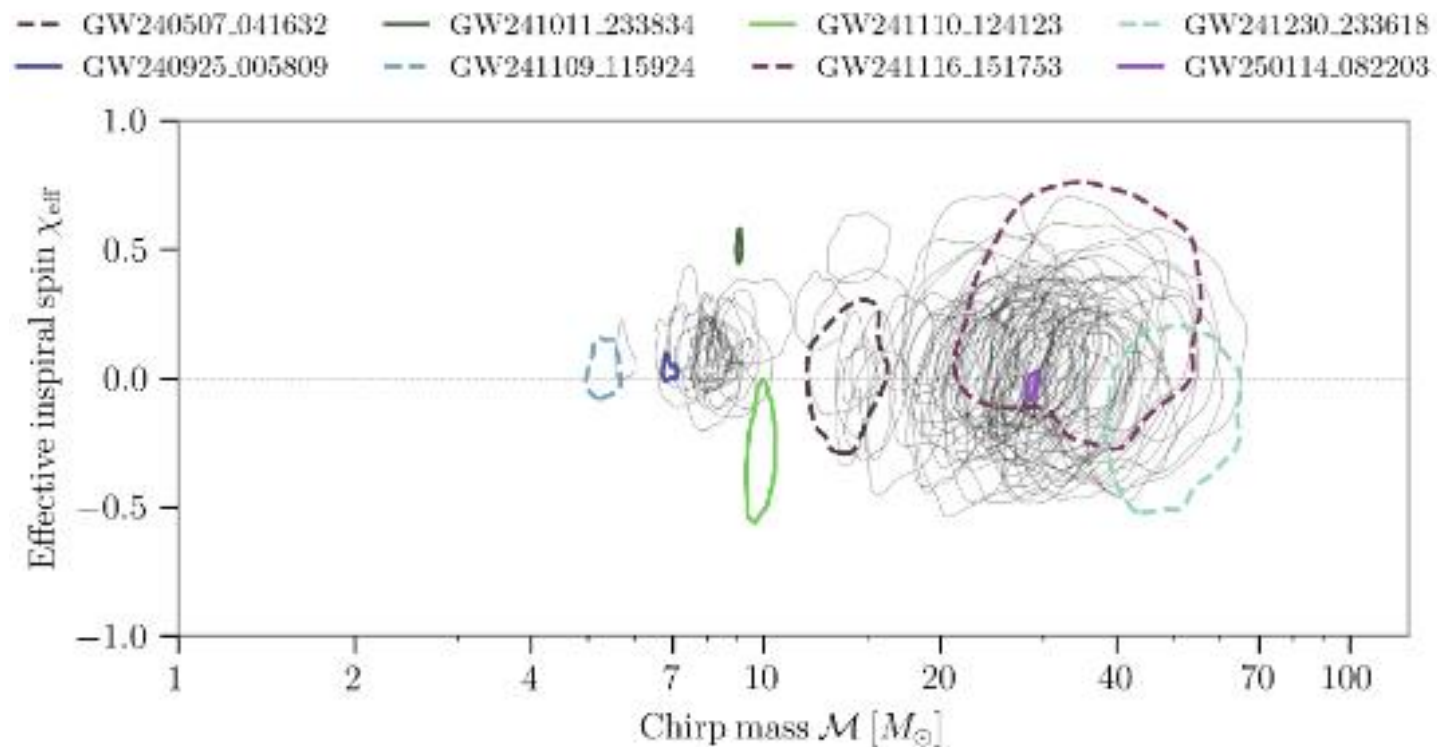
Masses

- All events consistent with binary black holes .
- All events within the range of GWTC-4.0 events.
- Four events may be intermediate mass black holes (above $100M_{\odot}$).
- Four events have support for unequal mass ratios.



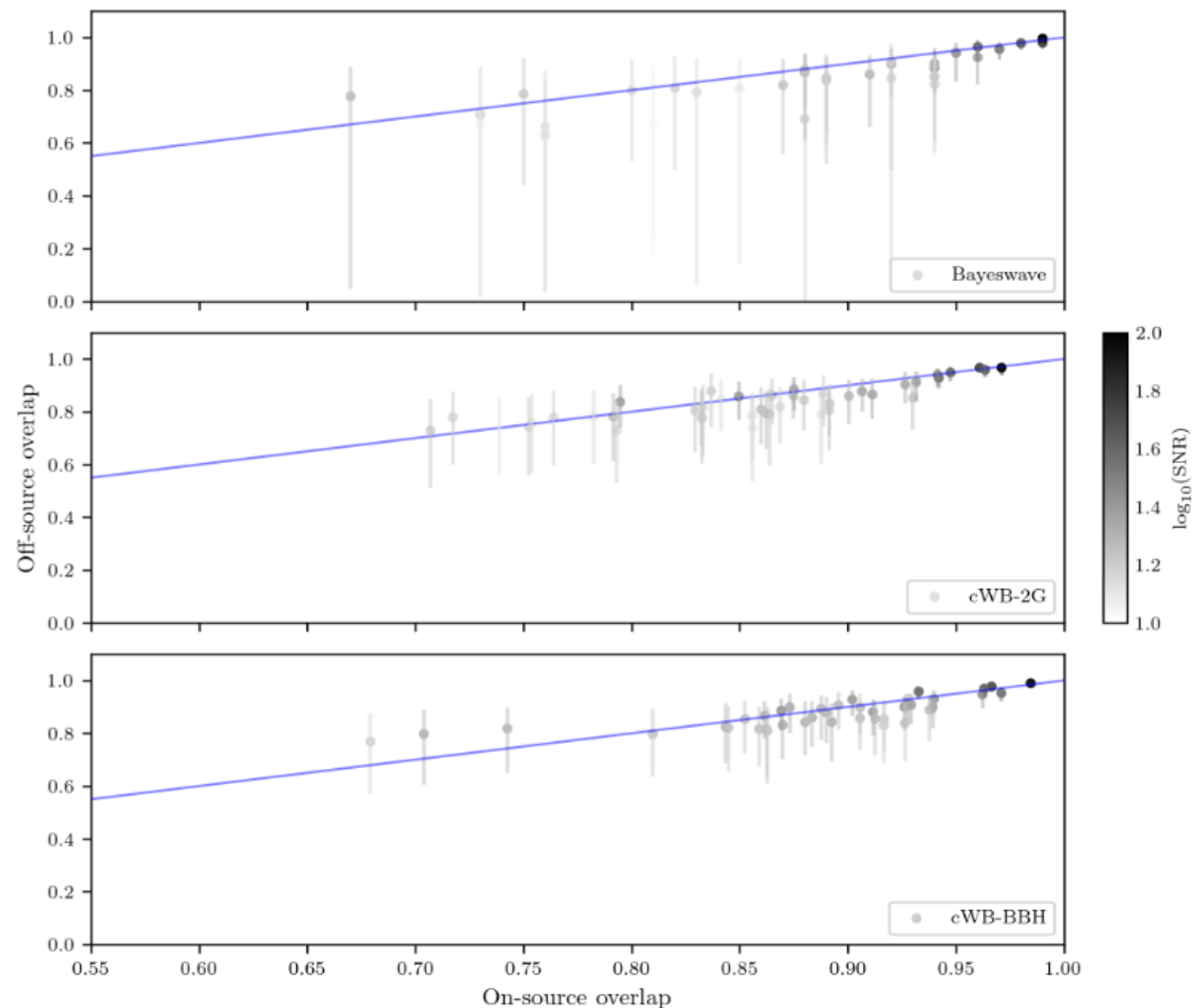
Effective Inspiral Spin

- Most events consistent with $\chi_{\text{eff}} = 0$. (random or no spin)
- Two events with support for $\chi_{\text{eff}} < 0$. (anti-aligned)
- Five events with support for $\chi_{\text{eff}} > 0$. (aligned)



Waveform Consistency Tests

- Three pipelines conducted an injection campaign where 43 injections derived from PE samples are reconstructed on off-source frame.
- Waveform overlap is calculated between injection and reconstruction.
- Overall, there is no significant difference between on-source and off-source overlaps.

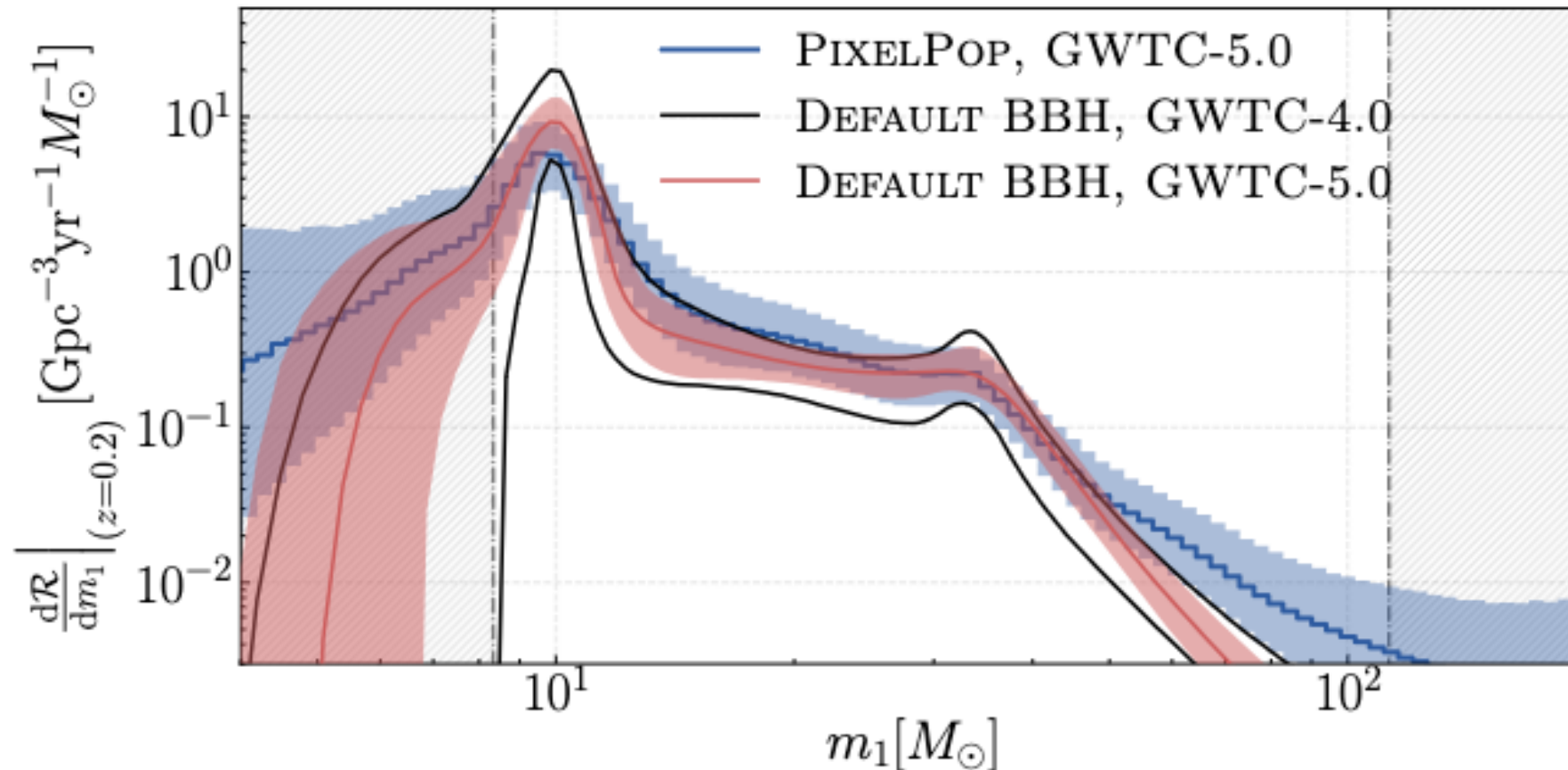


Rates & Populations

- Growing evidence for multiple sub-populations of black hole binaries.
- Distinct evidence of black holes with rapid spins in O4b.
- Rates for binary black hole mergers between $2.5 - 200 M_{\odot}$ updated to $18.0-30.8 \text{ Gpc}^{-3} \text{ yr}^{-1}$

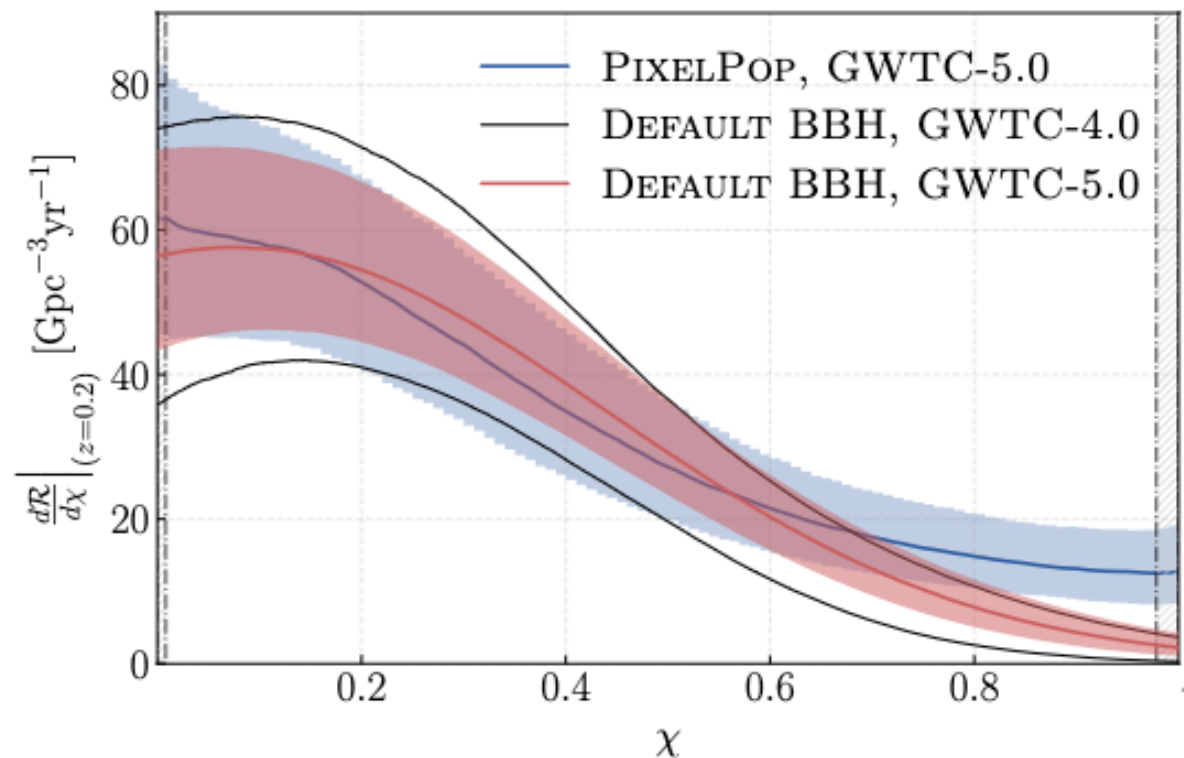
BBH Mass Distribution

- What is the reason for the peak at 10 solar masses?
- GWTC-5.0 results indicate the “bump” at 35 $M_{\odot}$ is just a change in slope rather than an over density.



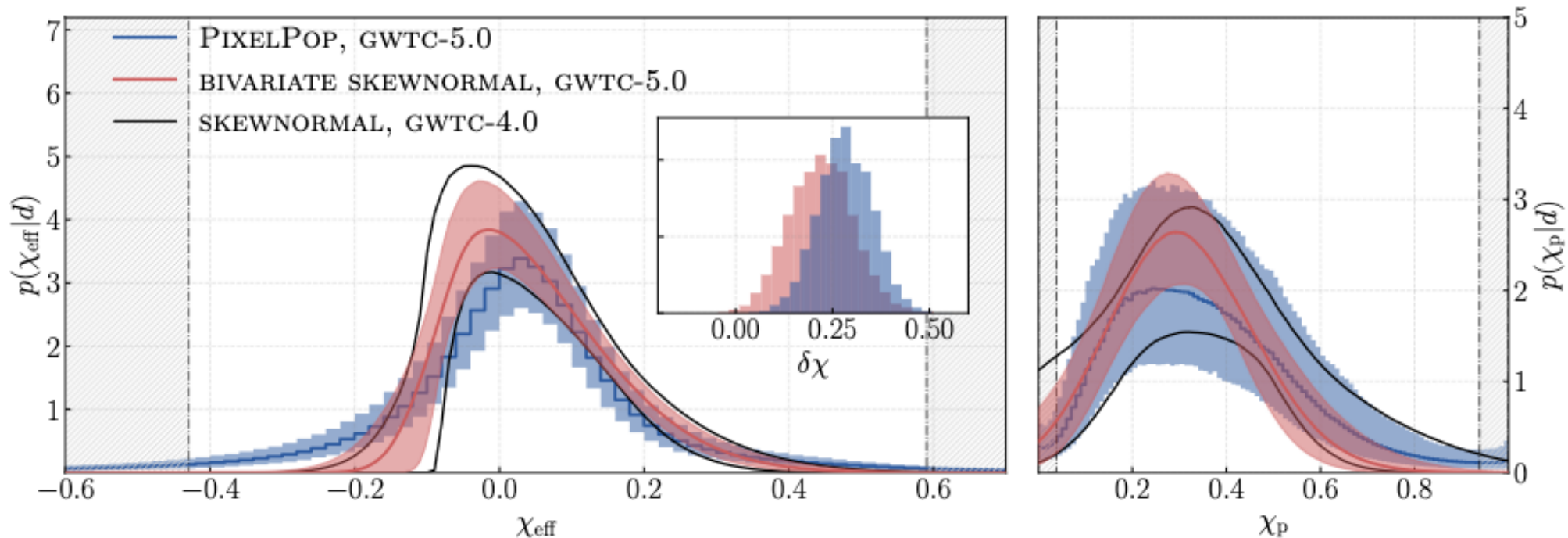
Component Spins

- Most BHs have small spins, 69 - 84% of BHs have $\chi < 0.5$
- When component spins are modeled independently, we find that about ~ 9 -24% of BBHs host at least one rapidly spinning BH ($\chi \sim 0.7$)

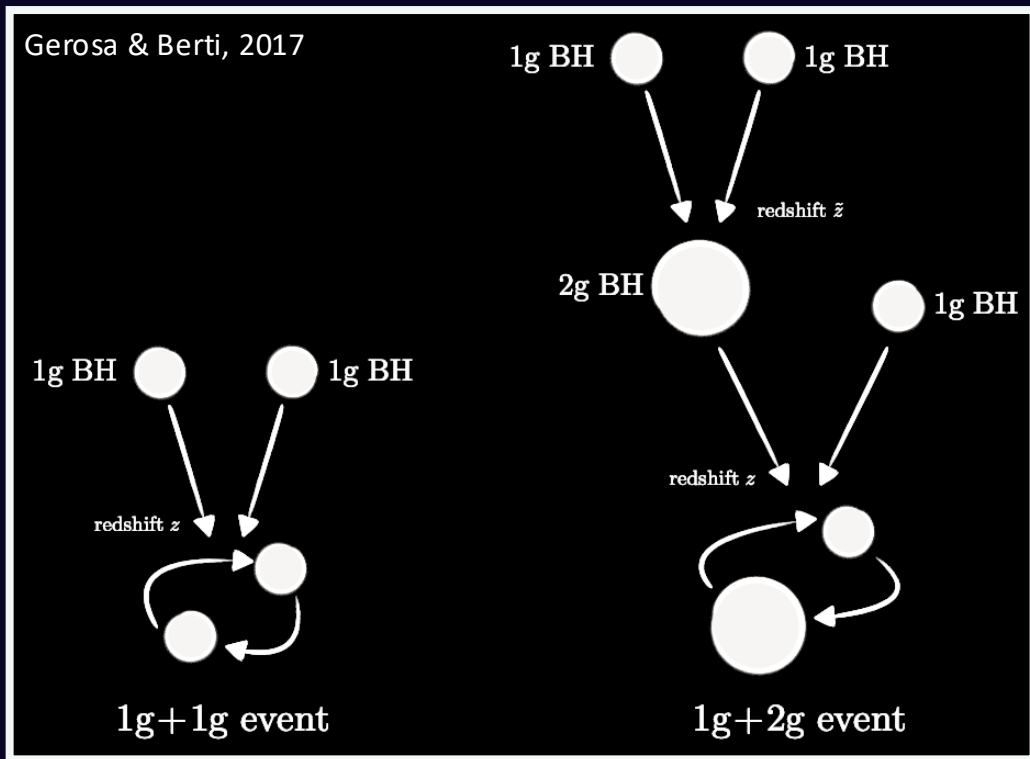


Effective Spins

- Asymmetry of the χ_{eff} distribution $\rightarrow$ at least 6% of binaries originate from preferentially aligned channels
- χ_p peaks away from zero, indicating some degree of precession in the population

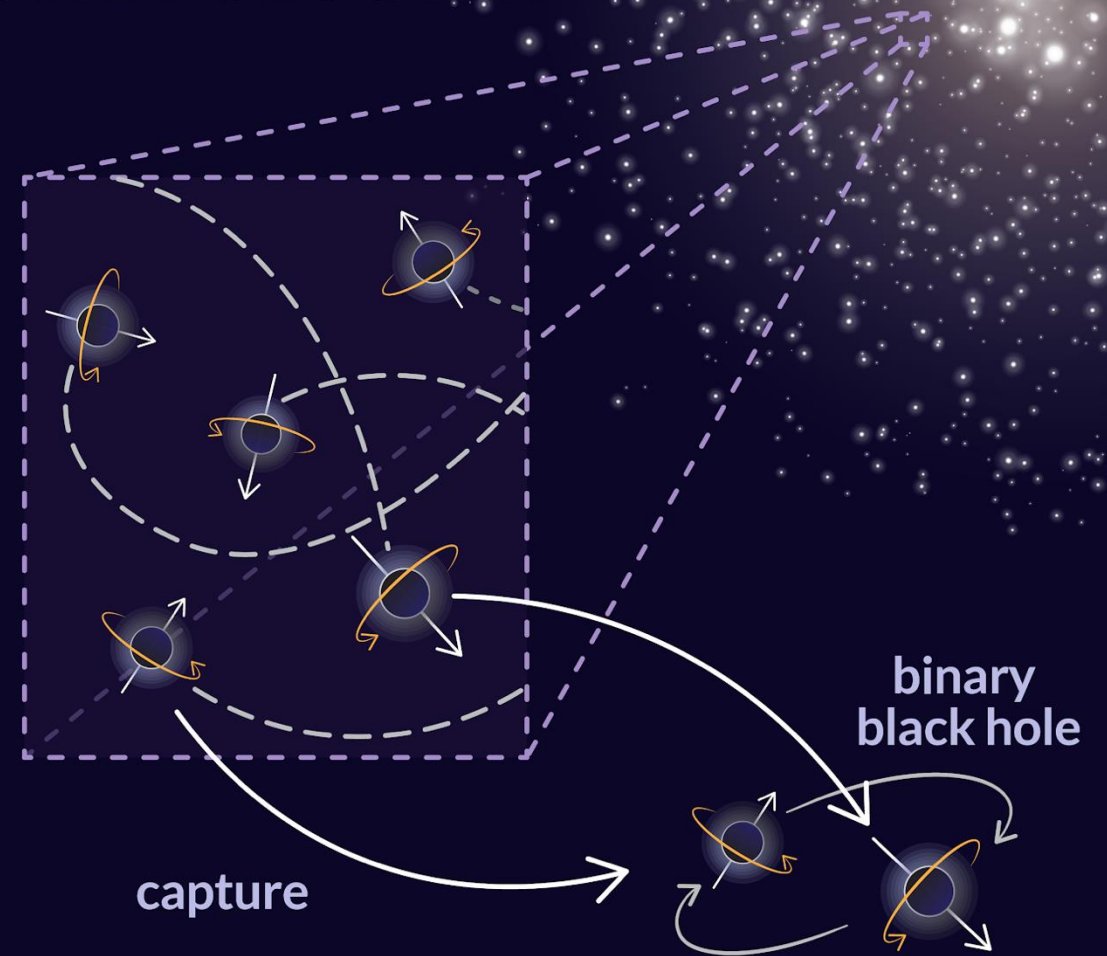


Hierarchical Mergers

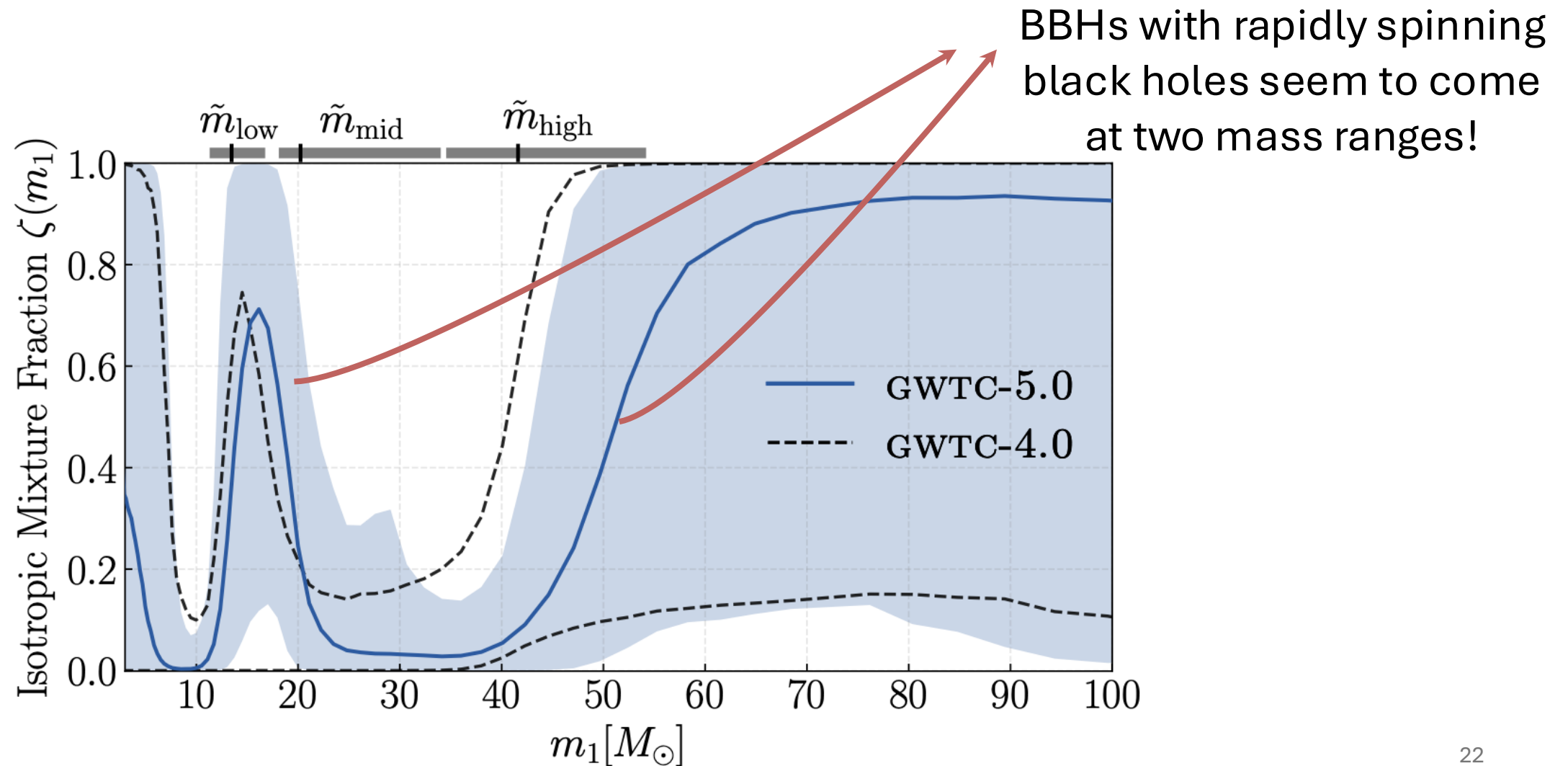


- Merger remnants have $\chi \approx 0.7$
- A 2G + 1G merger will have a rapidly spinning black hole ($\chi \approx 0.7$) with a slowly spinning one

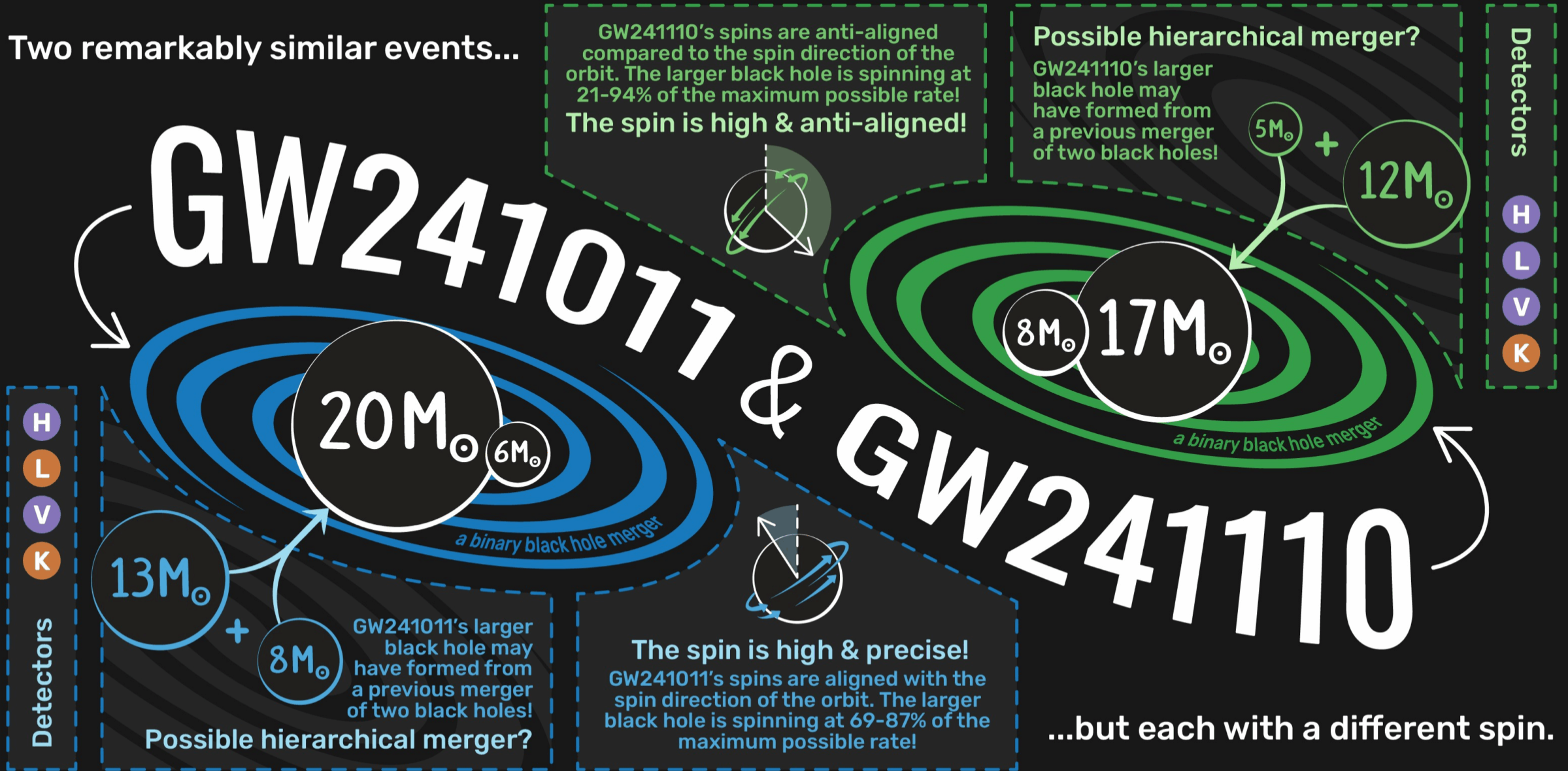
STAR CLUSTER



Signatures of hierarchical mergers



Two remarkably similar events...



● Online ● Offline

● H = LIGO Hanford ● V = Virgo

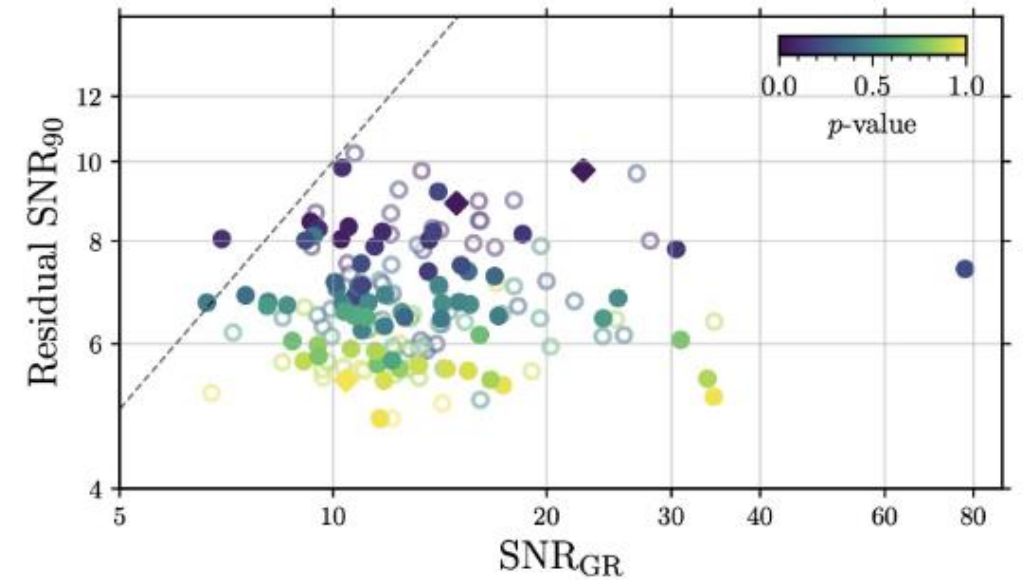
● L = LIGO Livingston ● K = KAGRA

@astronerdika

$M_{\odot}$ = Mass of the Sun
GW = Gravitational Wave

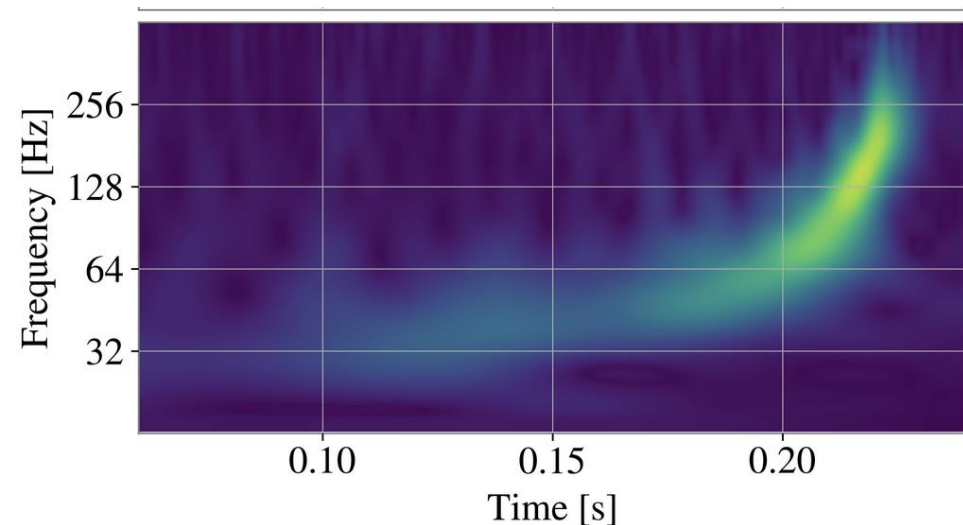
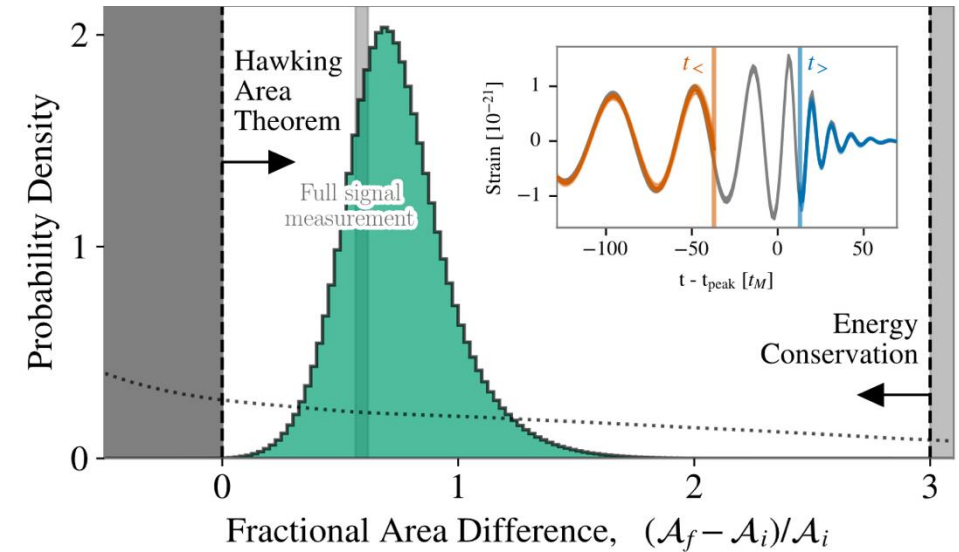
GWTC-5.0: Testing General Relativity

- Paper includes 8 different Tests of General Relativity.
- Only use 2+ detector events with a FAR less than equal to 10^{-3} yr⁻¹.
- The analysis uses 72 events from O4b.
- Also use 96 other events from previous observing runs.
- We find no evidence for deviations from the predictions of general relativity.



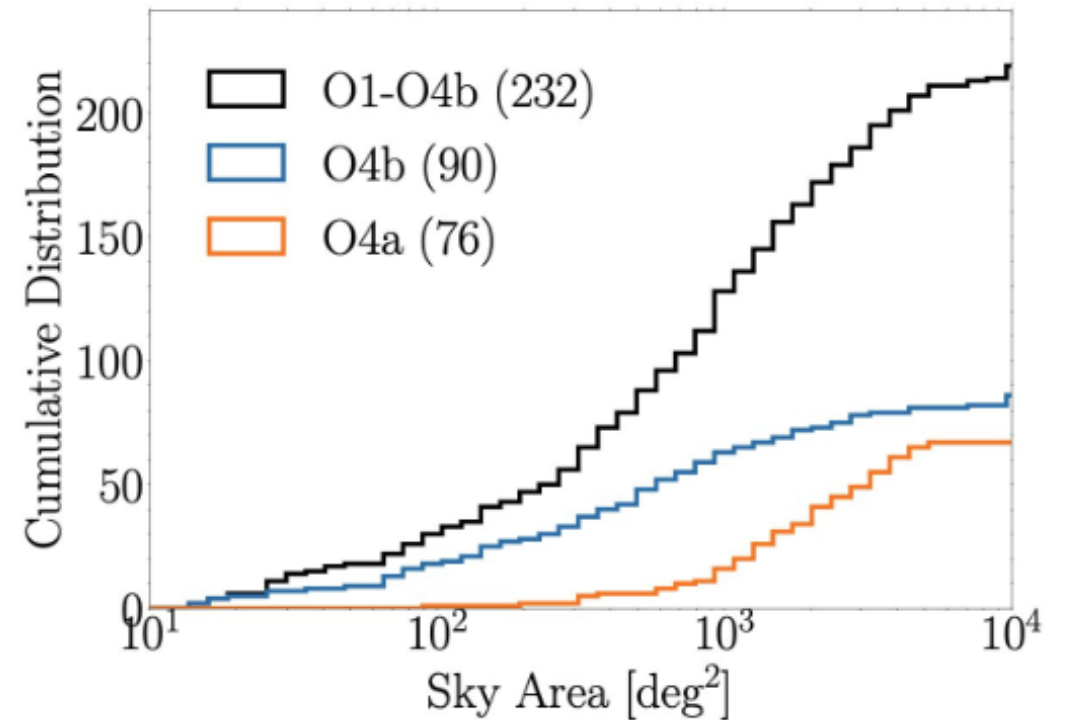
GW250114: Testing Hawking's area law

- Loudest ever event SNR ~ 80 .
- Louder events allow for better tests of GR.
- Can separately measure properties in inspiral and ringdown.
- Confirmed Hawking's area law to a high significance.
- arXiv:2509.08099



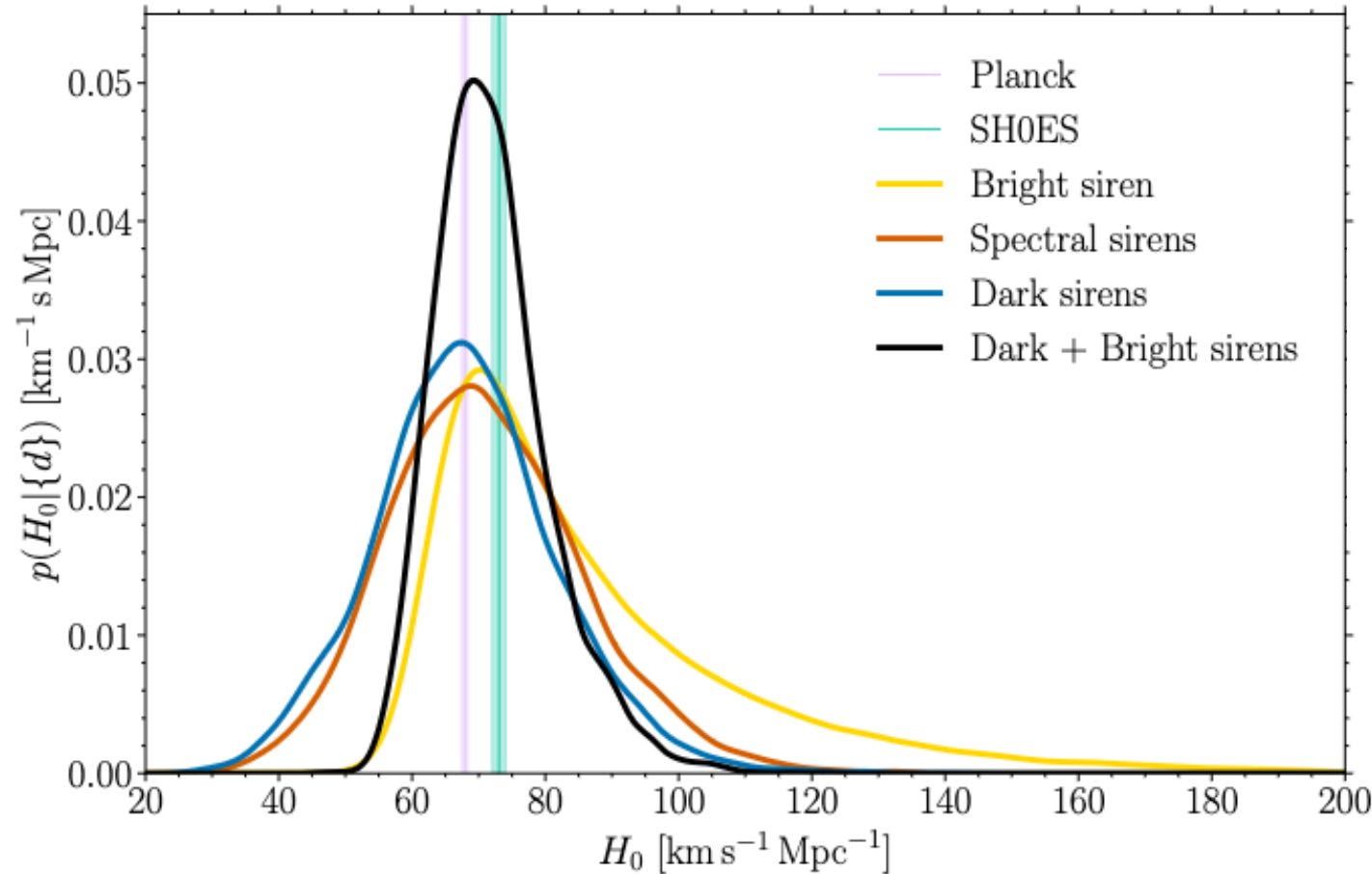
Constraints on Cosmic Expansion Rate

- Spectral sirens: Check the consistency of the features between the intrinsic and the detected population to infer the cosmological parameters.
- Dark sirens: Use galaxy catalog to reconstruct the possible redshifts of the GW events.



Events used in the analysis

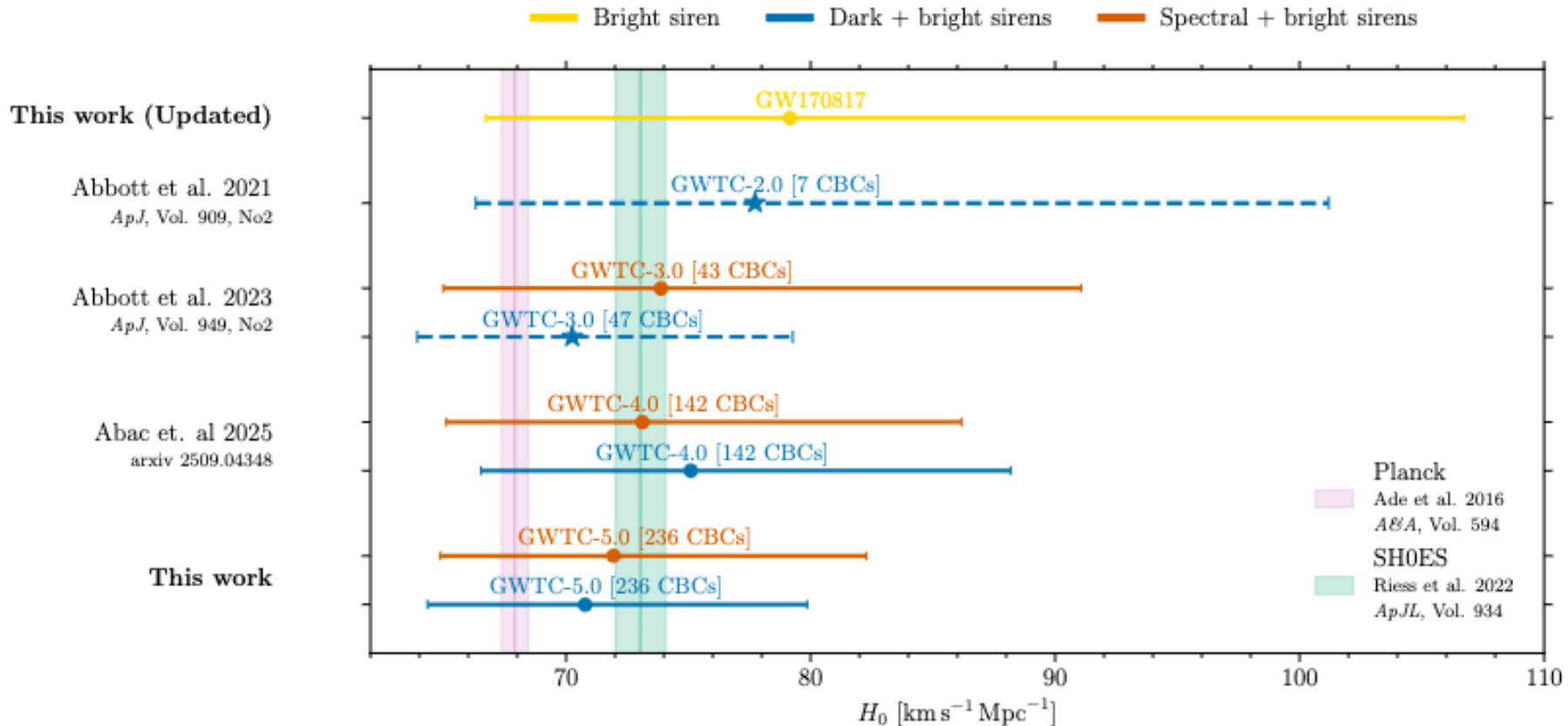
Constraints on Cosmic Expansion Rate



- **Spectral: $H_0 = 67.4 + 15.6 - 13.4$**
- **Dark: $H_0 = 67.5 + 15.3 - 13.0$ (DES)**
- **Bright + dark: $H_0 = 71.4 + 9.9 - 7.6$**

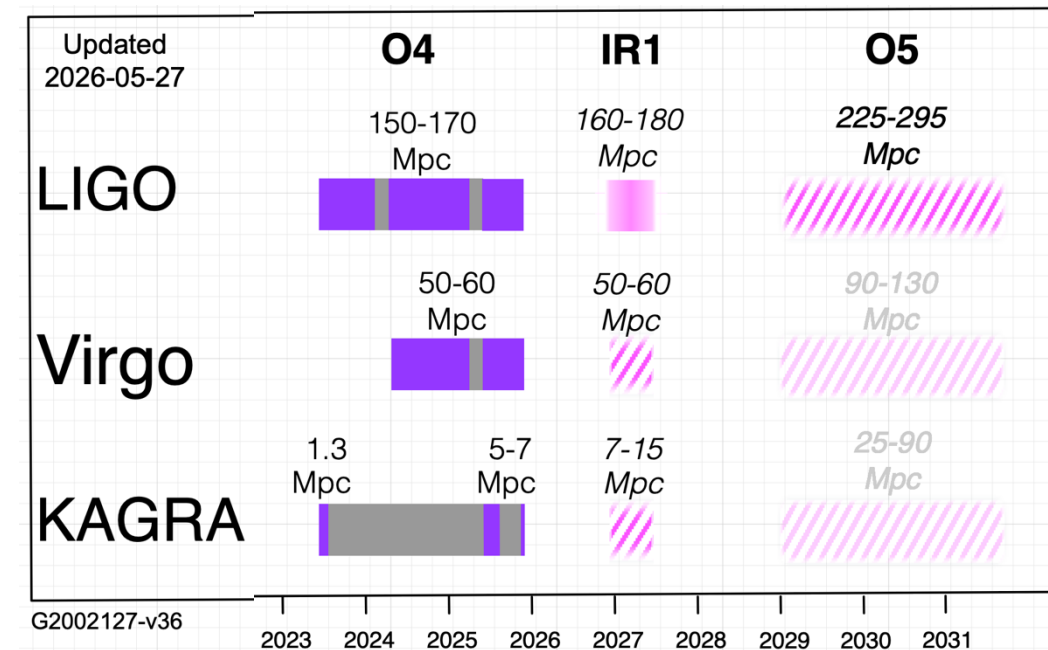
Measurements Over Time

- Improvement H_0 uncertainty (GWTC-4.0 vs GWTC-5.0):
 - Spectral siren: 16%
 - Dark siren: 19% (DES) and 17% (Glade+)



What is next for LIGO-Virgo-KAGRA?

- GWTC-6 focus issue is in progress!
- Release of O4c data and papers is planned for December 2026.
- Next Observing Run **IR1** (Intermediate Run 1)
 - 6 months duration
 - Current plan to start between late October and mid-November of 2026.
- See observing plans page for regular updates
<https://observing.docs.ligo.org/plan/>



Conclusions

- This year LIGO-Virgo-KAGRA released O4b data containing 161 new black hole events.
- More events allows us to better understand the population properties and understand black hole formation channels.
- Louder events are enabling precision tests of general relativity.
- More to come later this year!