10th Anniversary of the Discovery of Gravitational Waves
19 September 2025

Latest results from the LIGO-Virgo-KAGRA Collaboration

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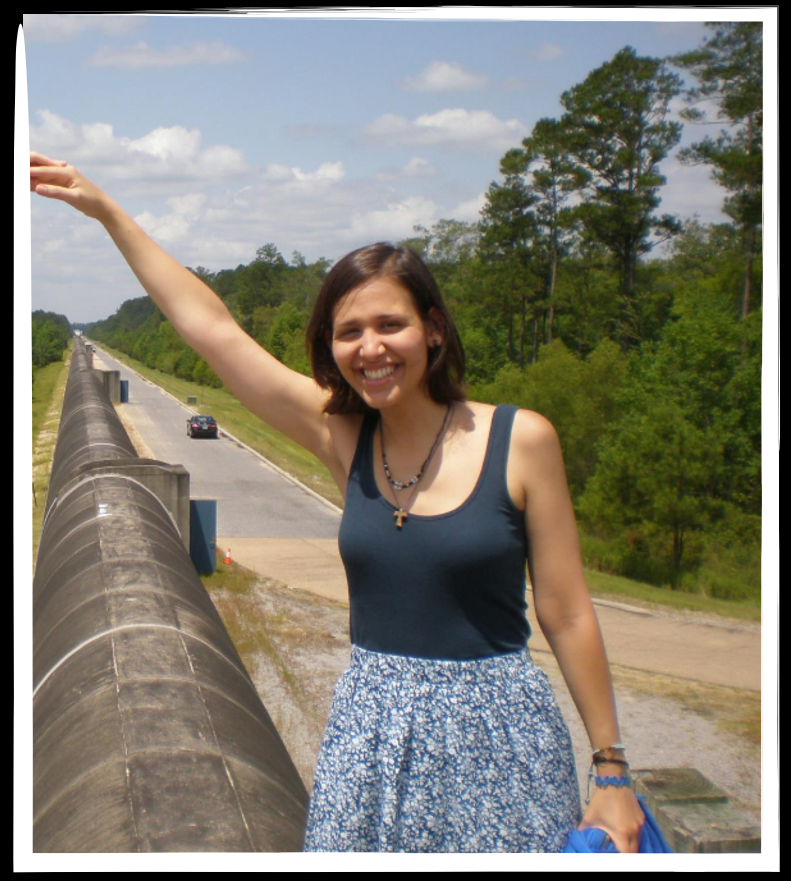
MAX-PLANCK-GESELLSCHAFT

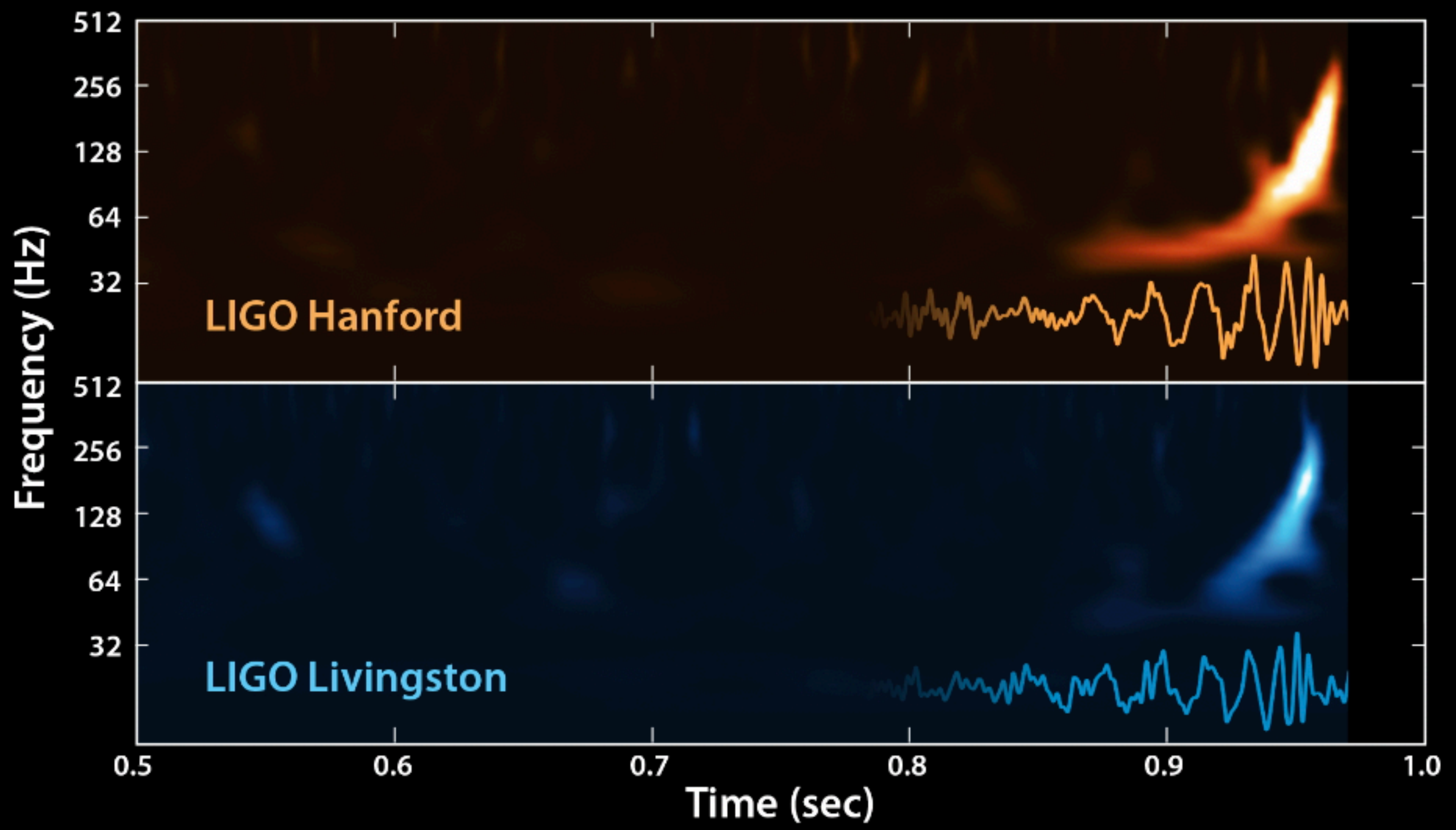
MARIE CURIE ACTIONS

Funded by the European Union

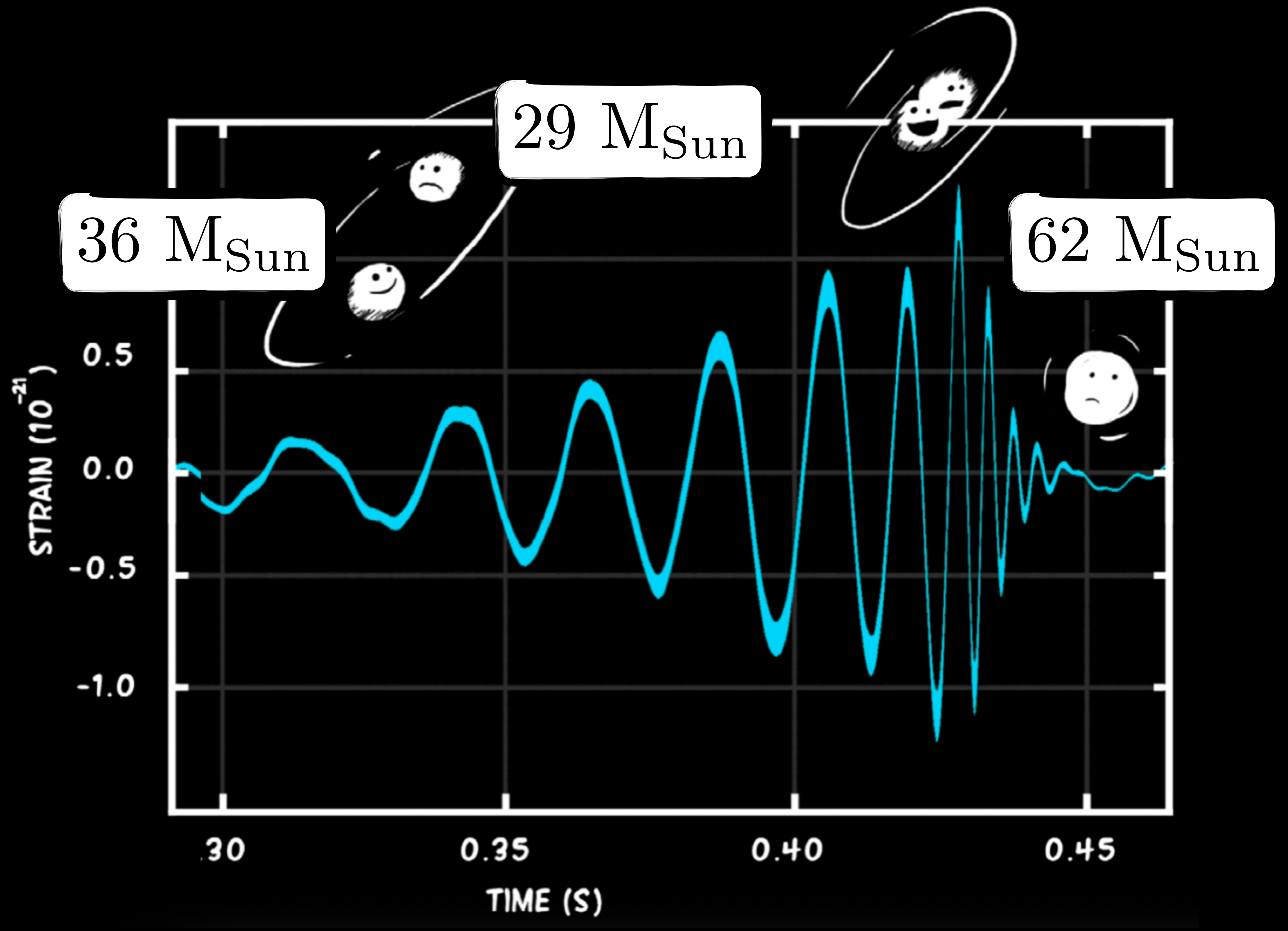
GW150914

The first observation of gravitational waves from a binary black hole merger



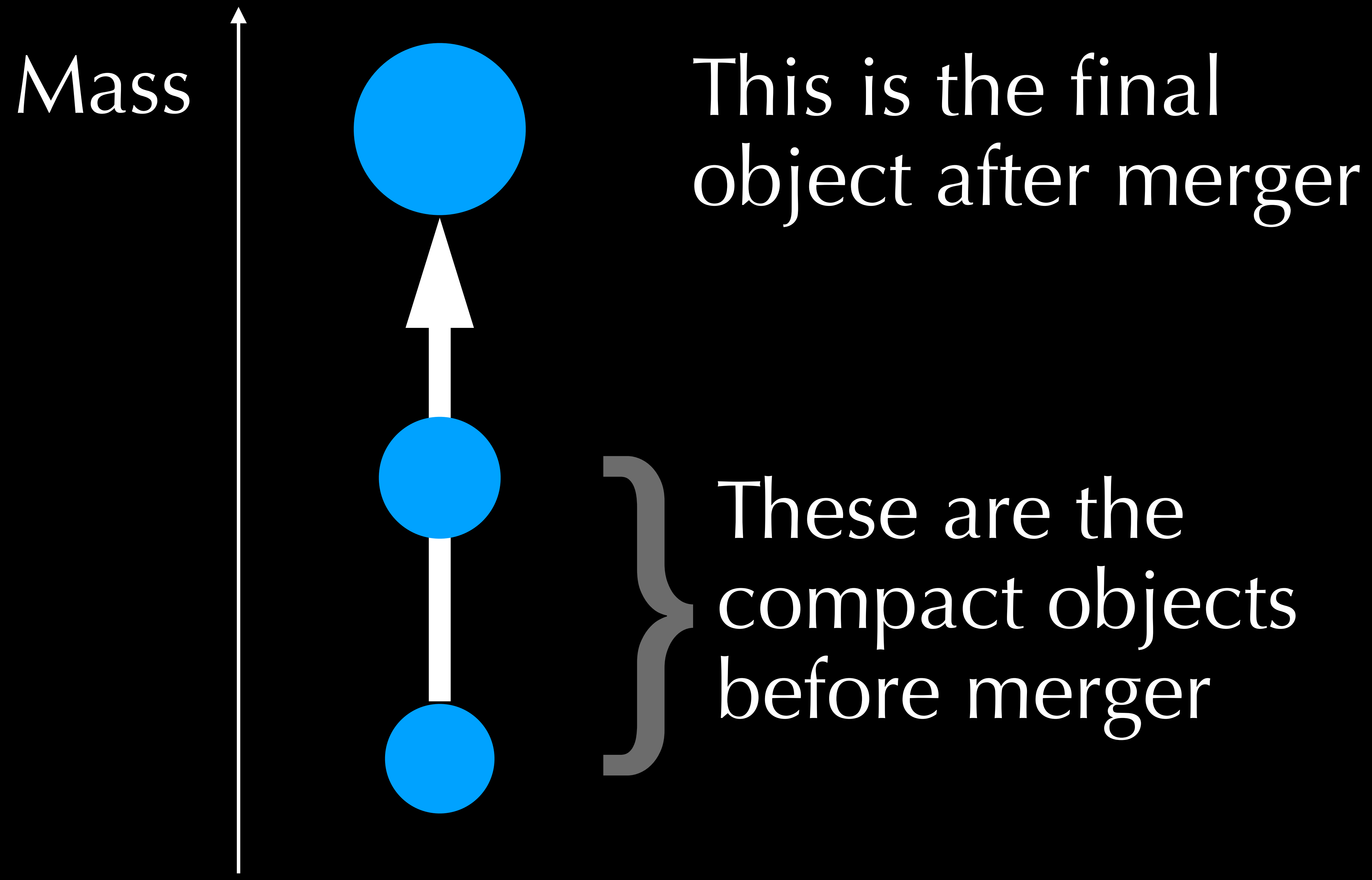


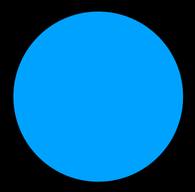
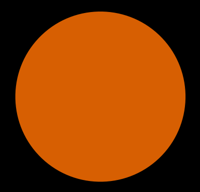
Signal-to-noise ratio = 24



https://www.ligo.org/magazine/LIGO-magazine-issue-8.pdf

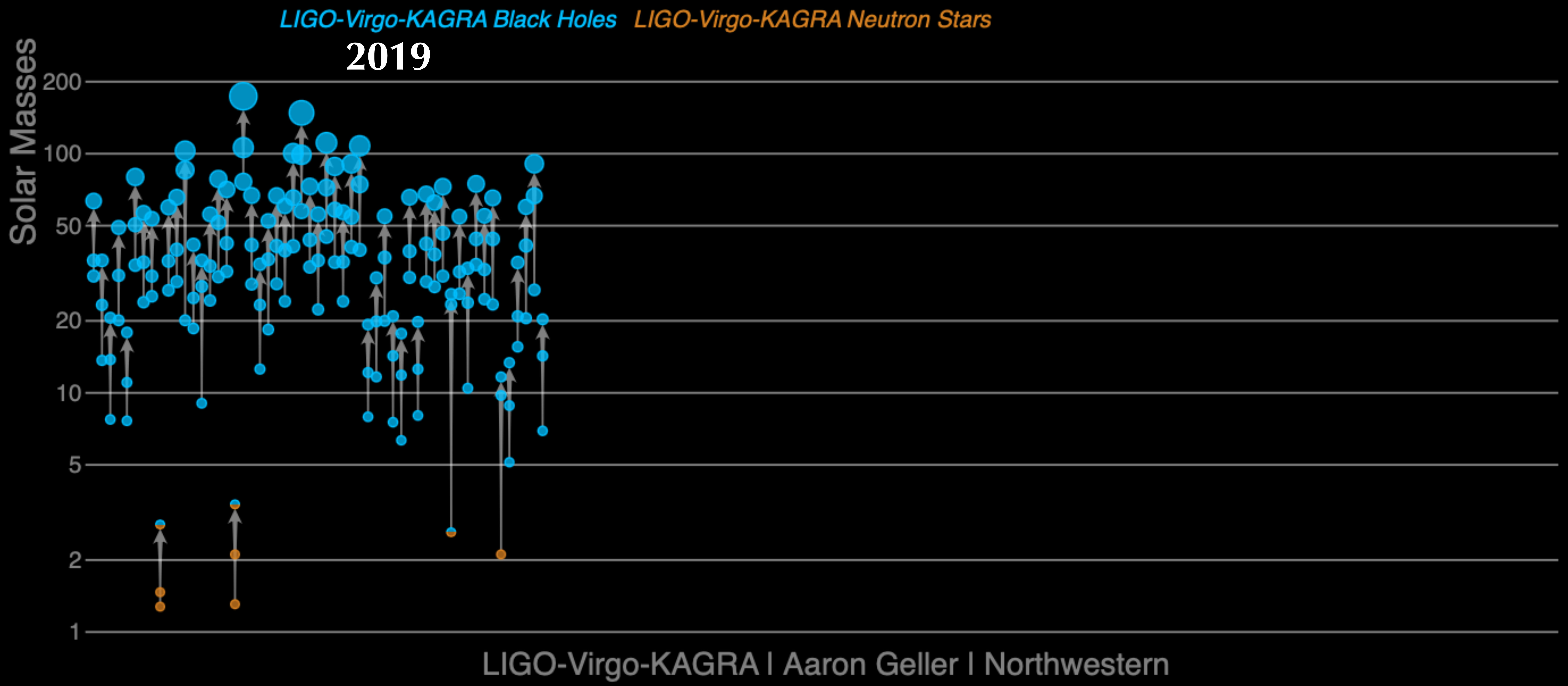
How many detections have we had?



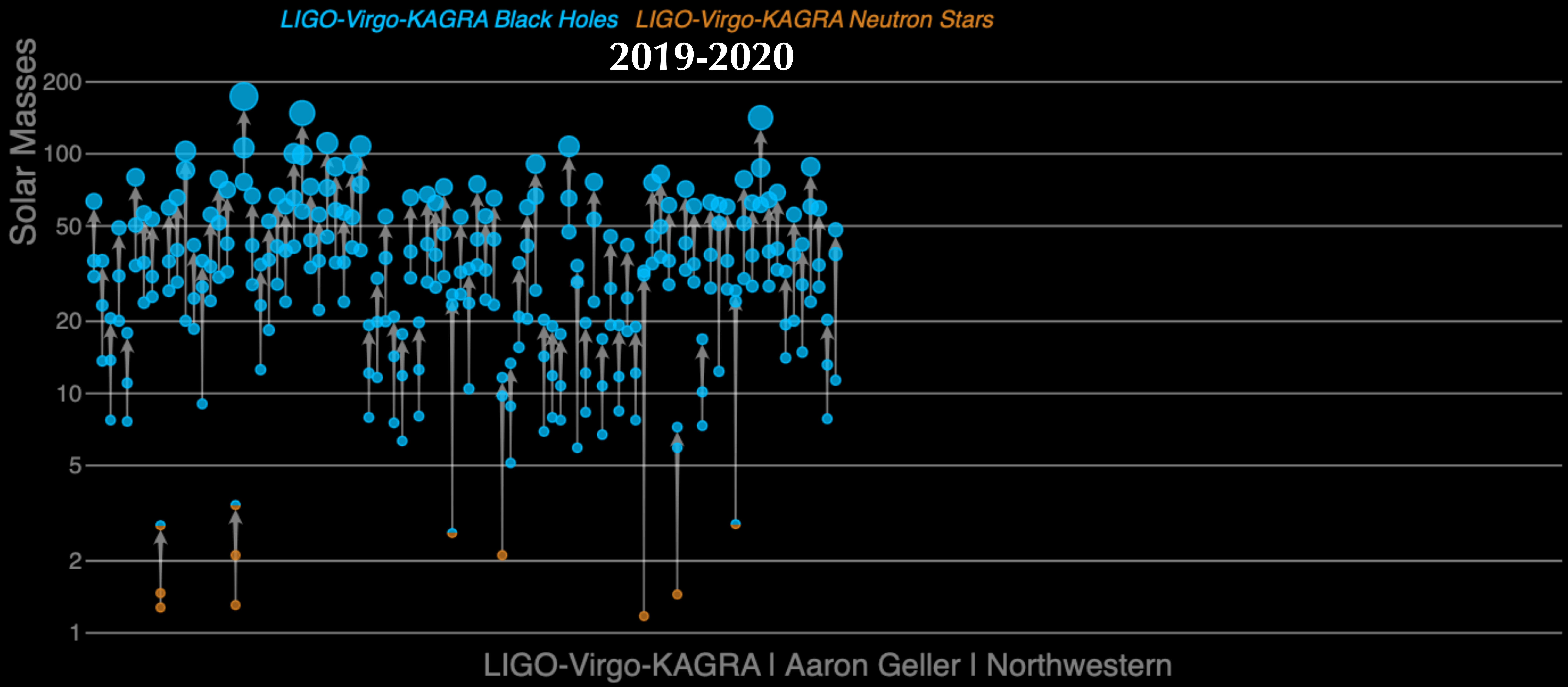
Black Holes  and Neutron Stars 

Gravitational-wave events

Gravitational-wave events

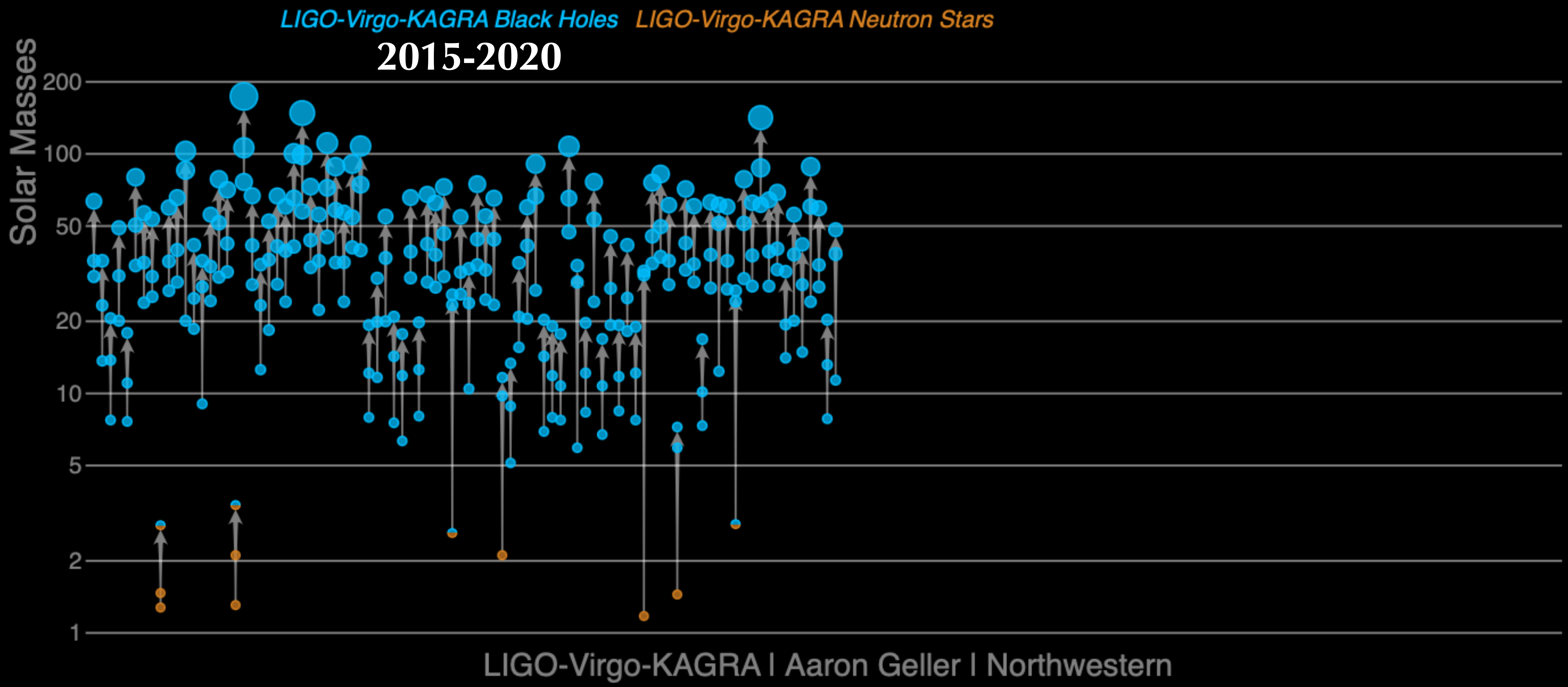


Gravitational-wave events

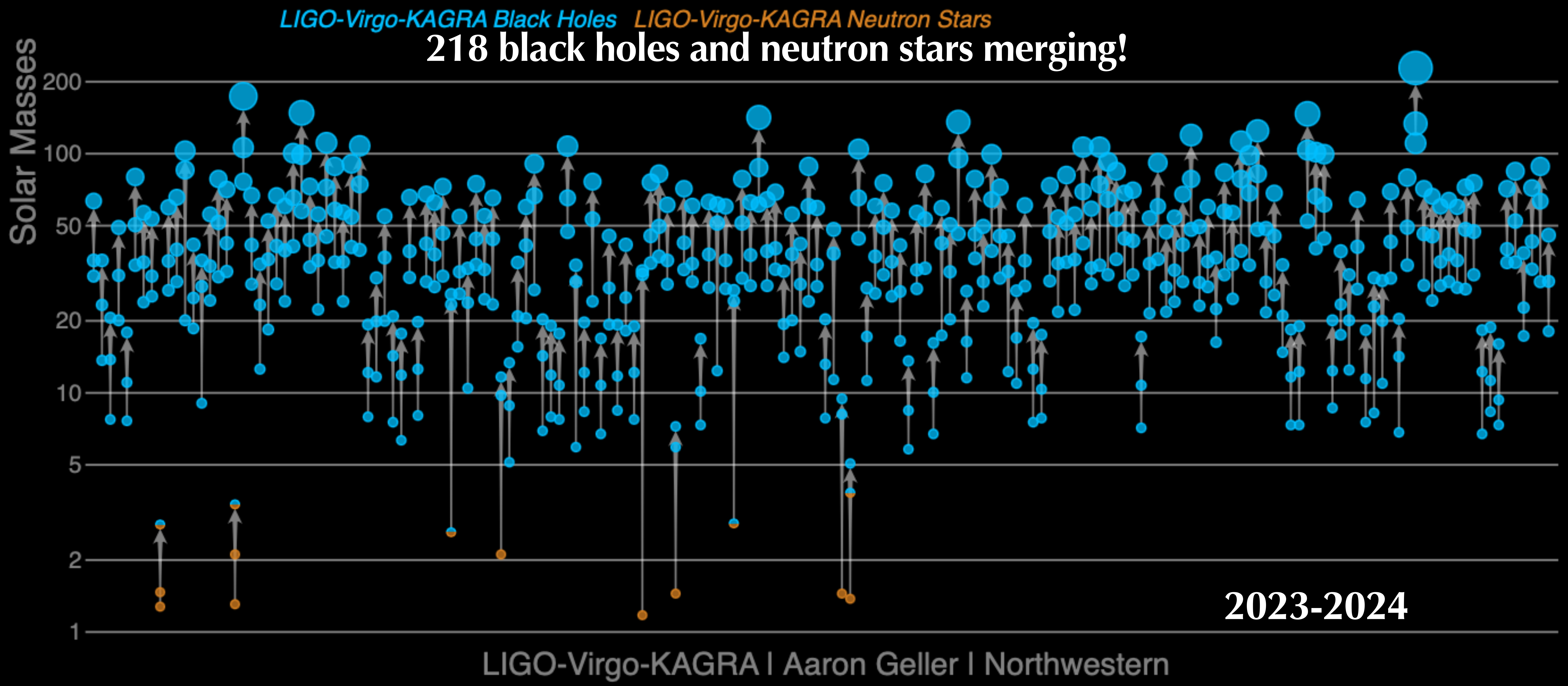


New Results from the LIGO-Virgo-KAGRA Collaboration

Gravitational-wave events



Gravitational-wave events

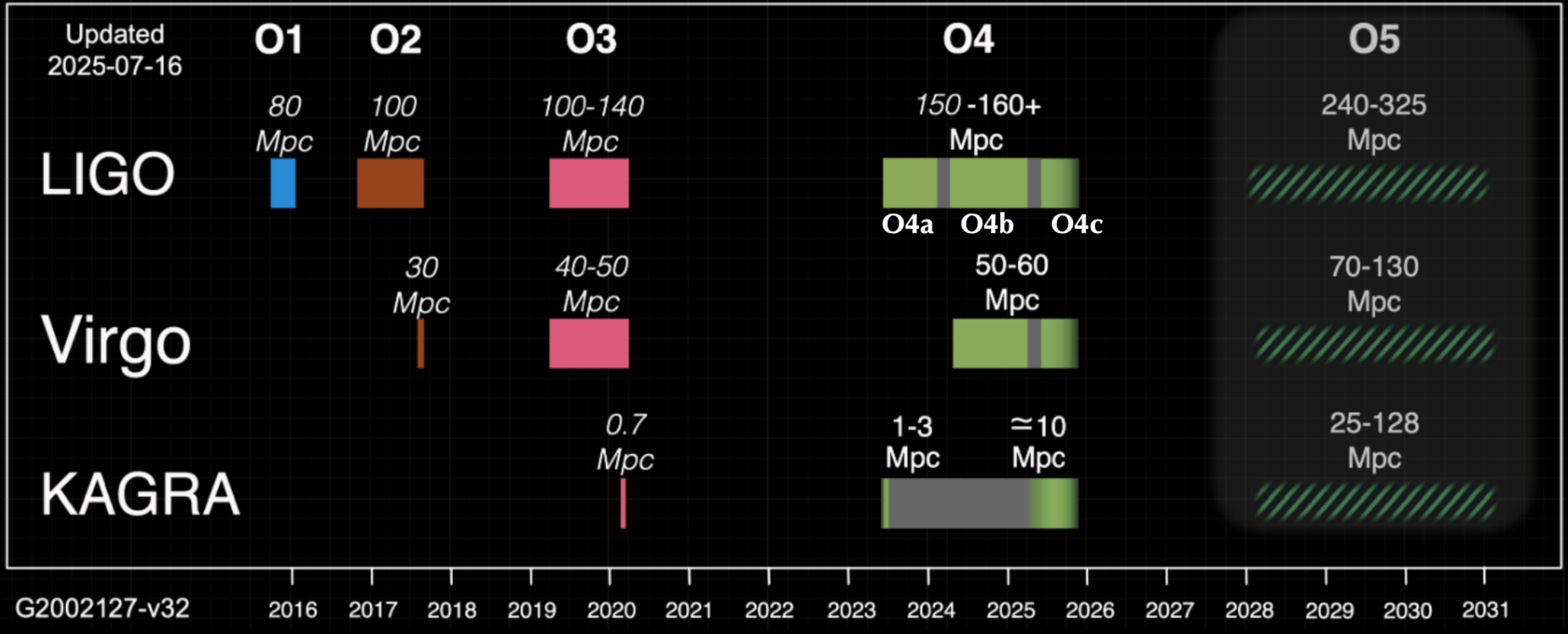


The observing runs

O4a: May 2023 - January 2024

O4b: April 2024 - January 2025

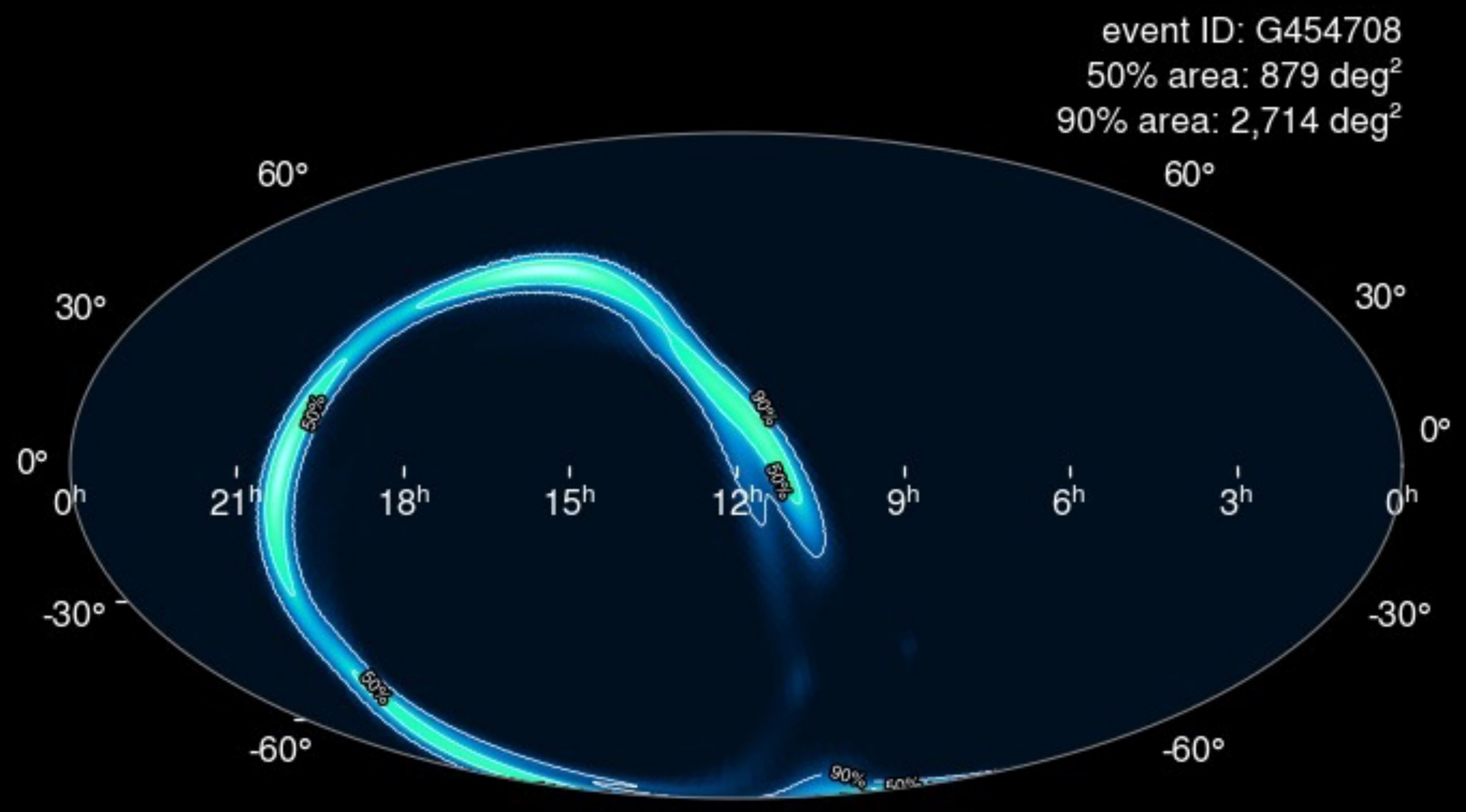
O4c: January 2025 - November 2025



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

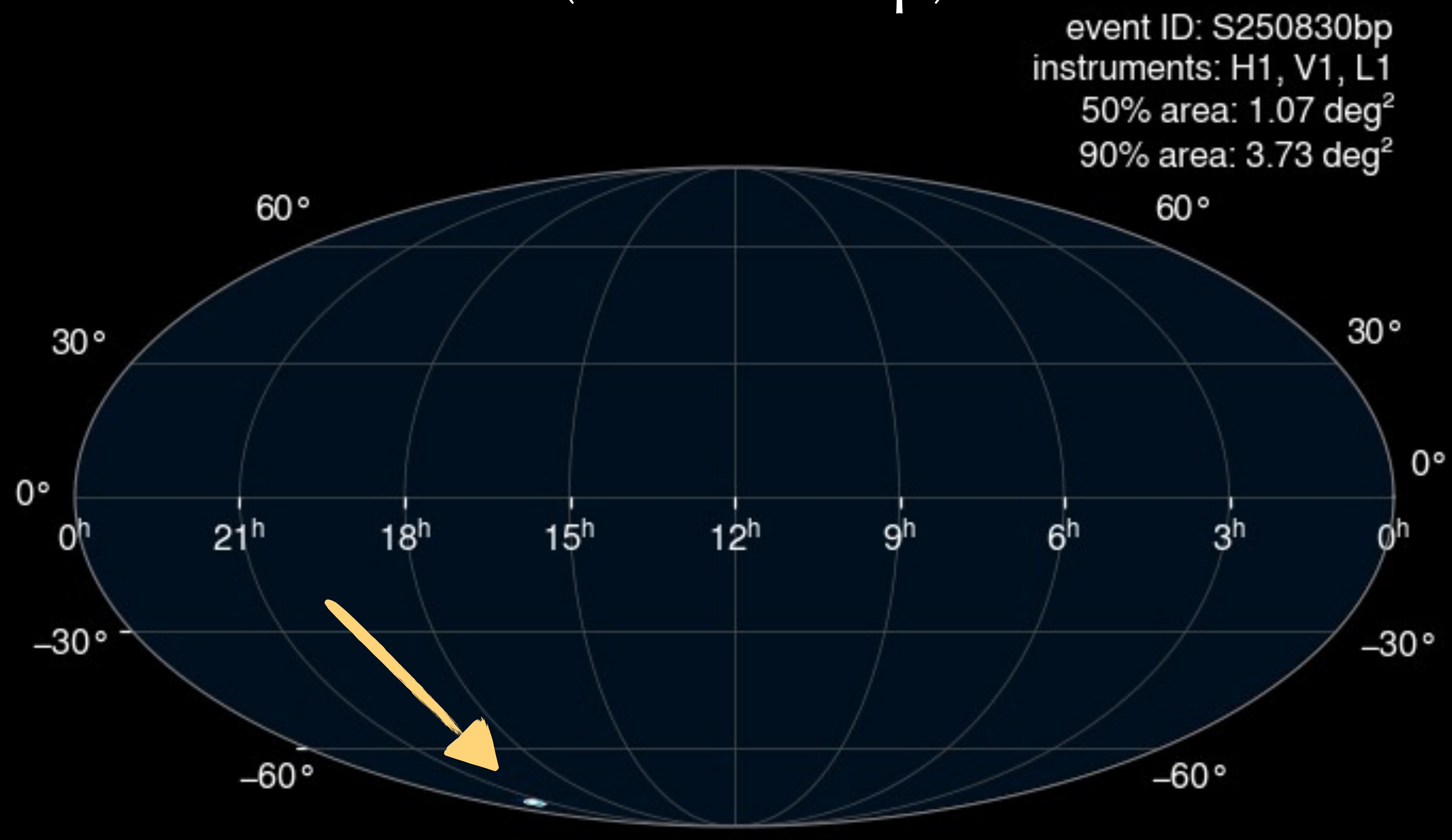
The sky localization

O4a (GW231123)



Hanford, Livingston

O4c (S250830bp)

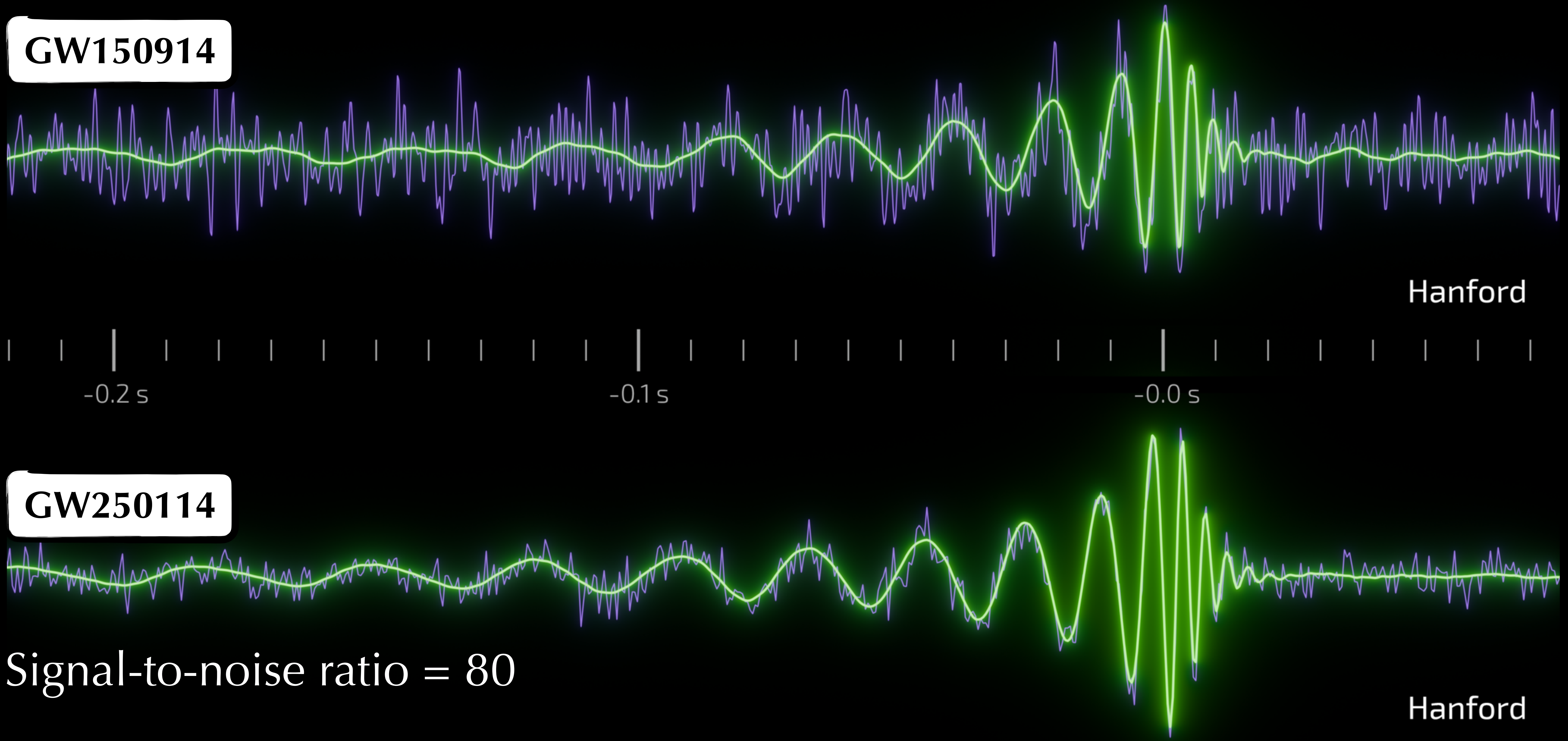


Virgo, Hanford, Livingston

https://gracedb.ligo.org

GW250114

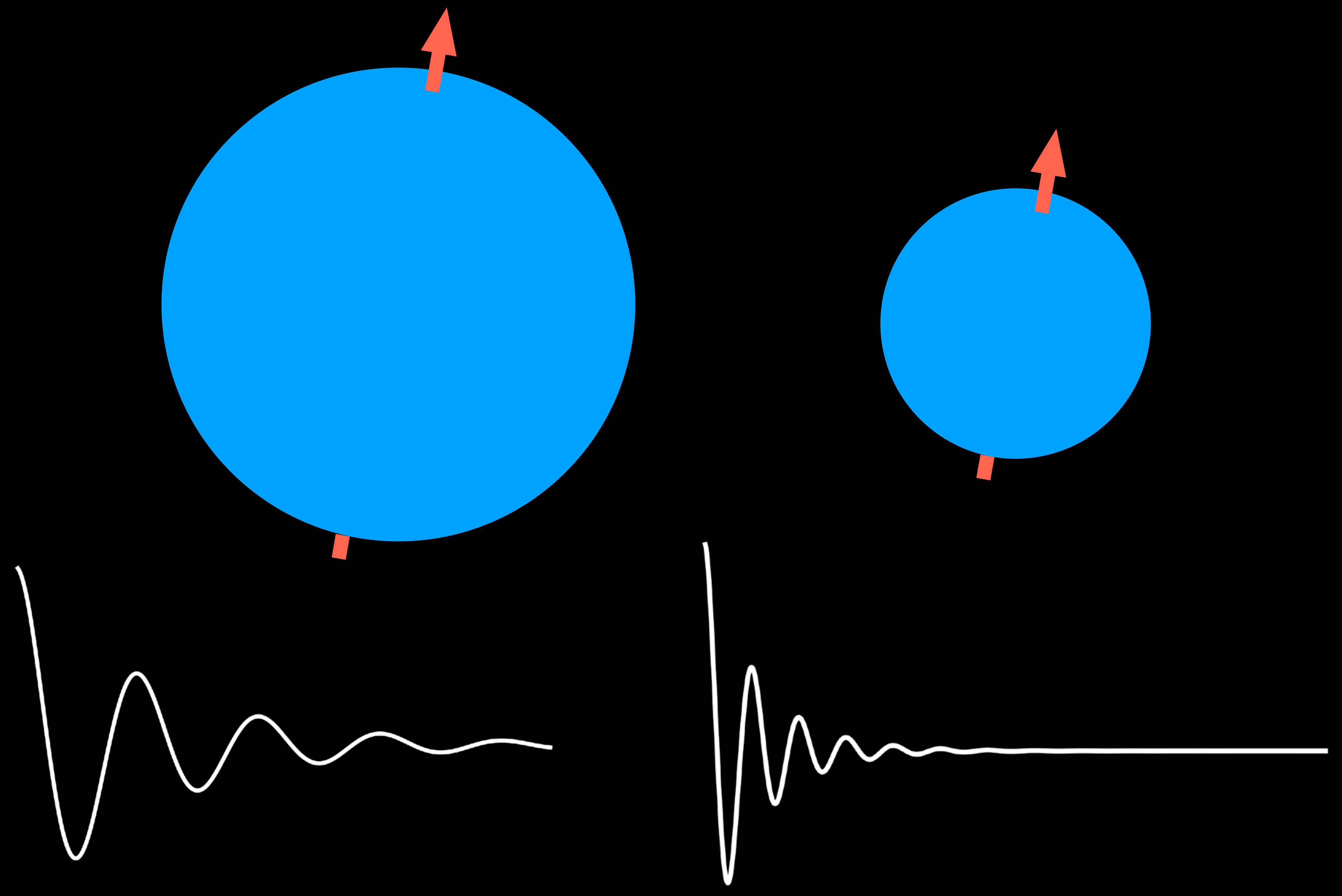
The clearest view yet of merging black holes



Signal-to-noise ratio = 80

Credit: J. Tissino (GSSI)/R. Hurt (Caltech-IPAC)

Black holes ringdown



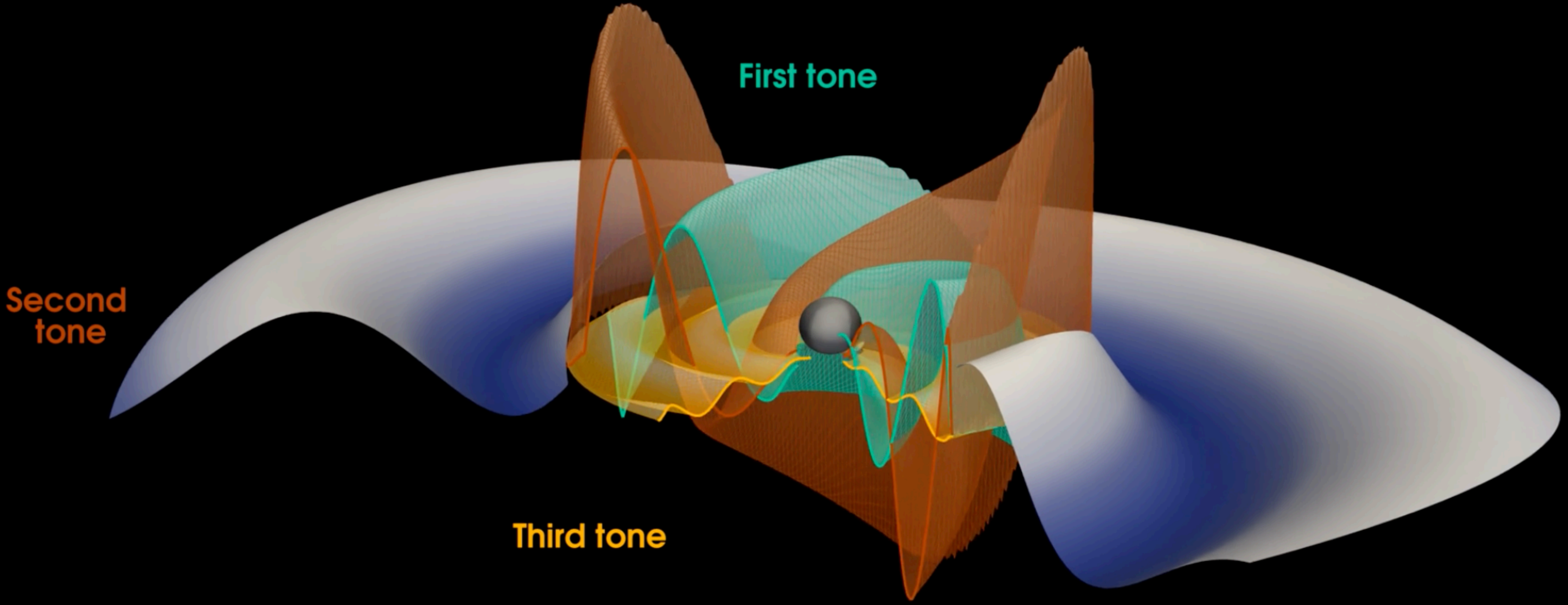
Black holes "ring" after a merger.

Black holes are simple objects that are only described by two numbers: their mass and spin.

Other objects would ring differently.

Credit: L. Pompili

GW250114



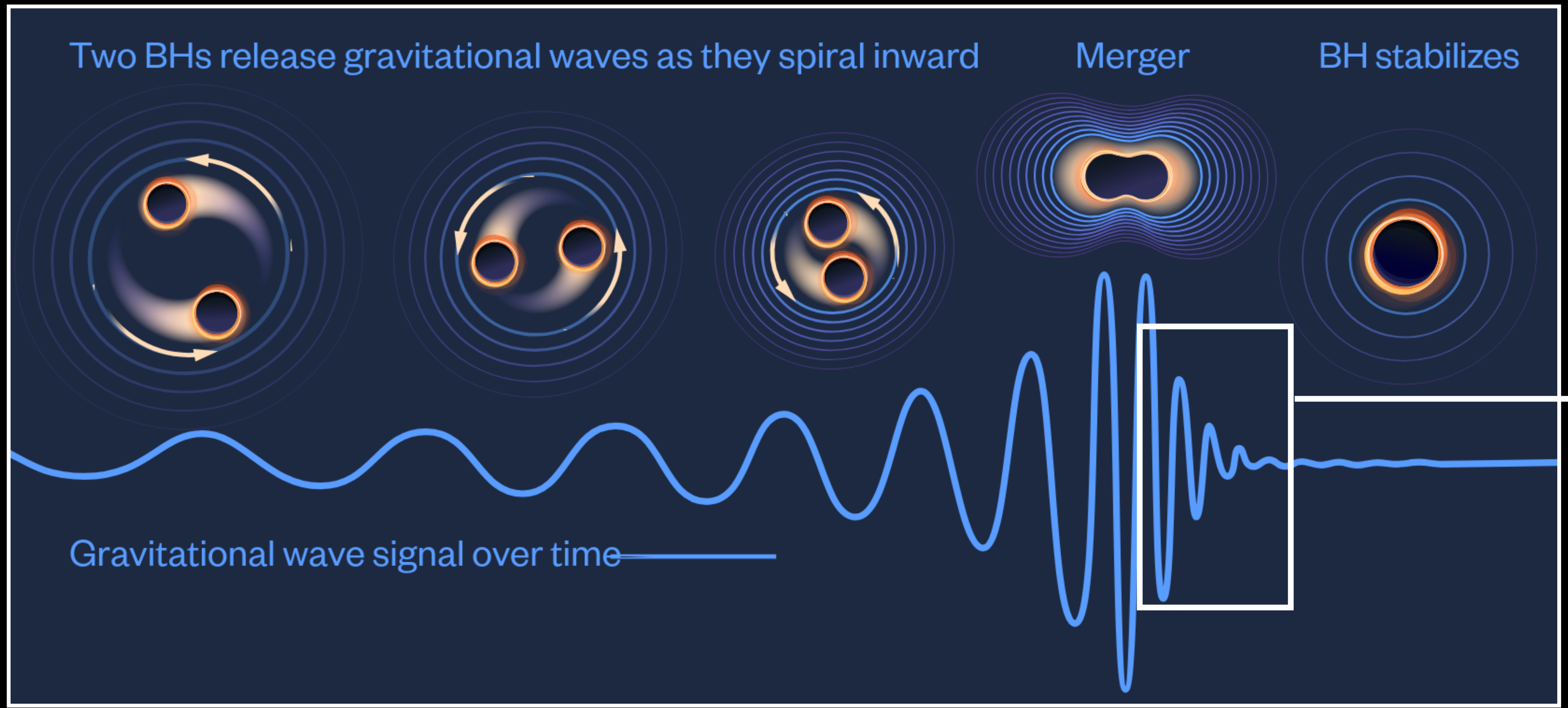
MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS (ALBERT EINSTEIN INSTITUTE)

The ringdown

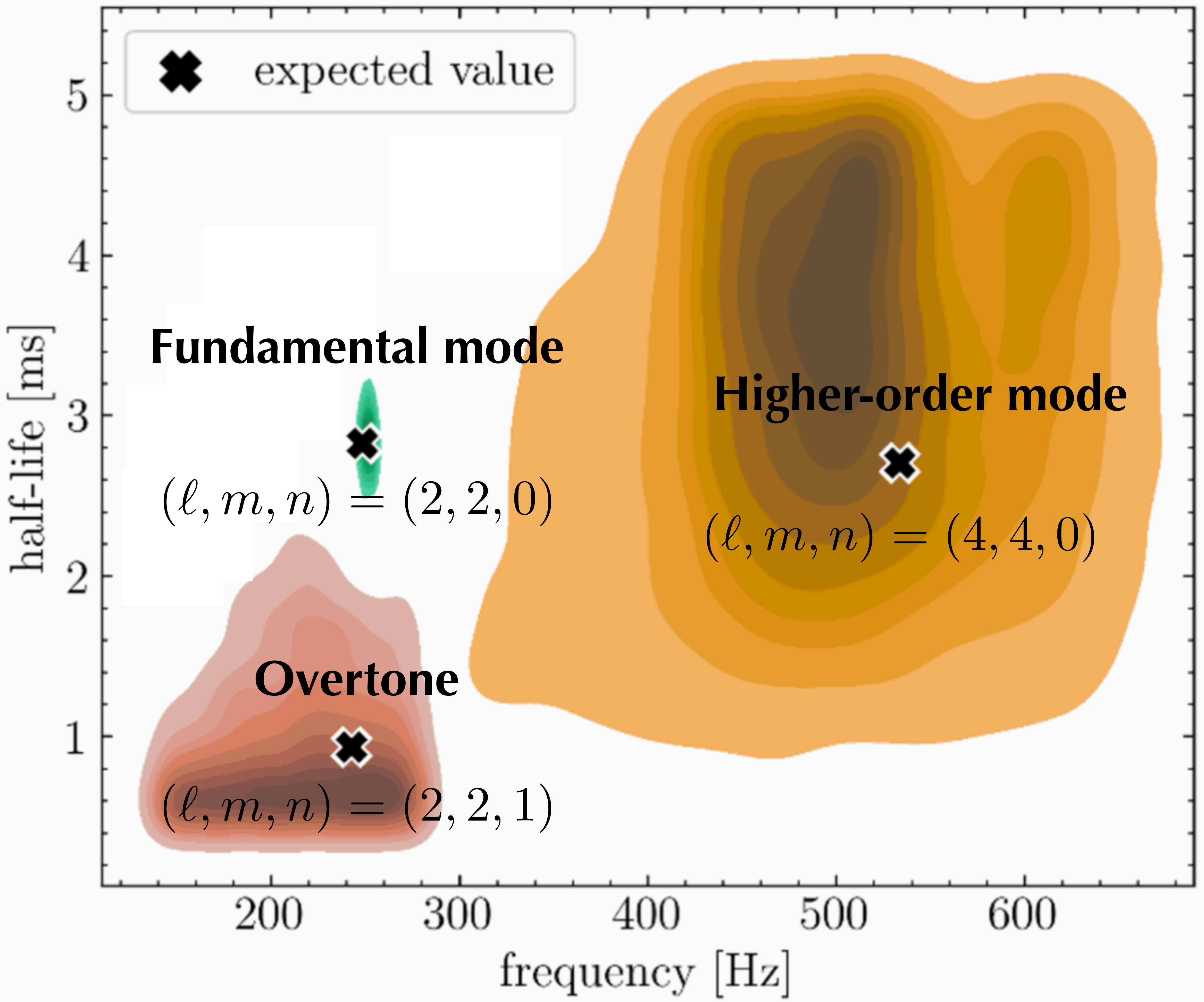
The ringdown is dominated by characteristic oscillations known as quasi-normal modes:

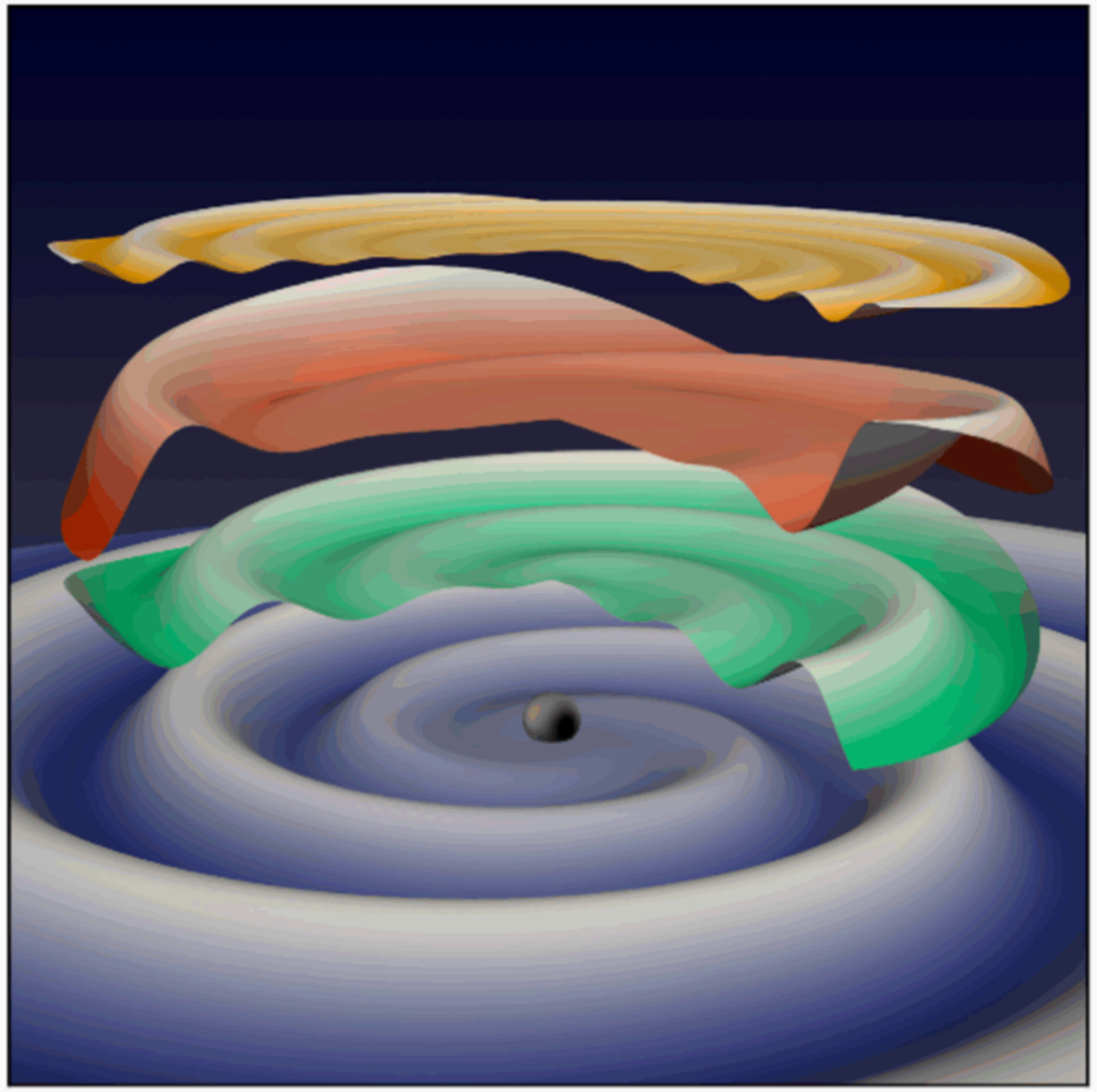
$$\omega_{\ell mn} = \omega_{R,\ell mn} + i\omega_{I,\ell mn}$$

It is modeled as a sum of exponentially damped sinusoids: $f_{\ell mn} = \dfrac{\omega_{R,\ell mn}}{2\pi}$, $\tau_{\ell mn} = -\dfrac{1}{\omega_{I,\ell mn}}$



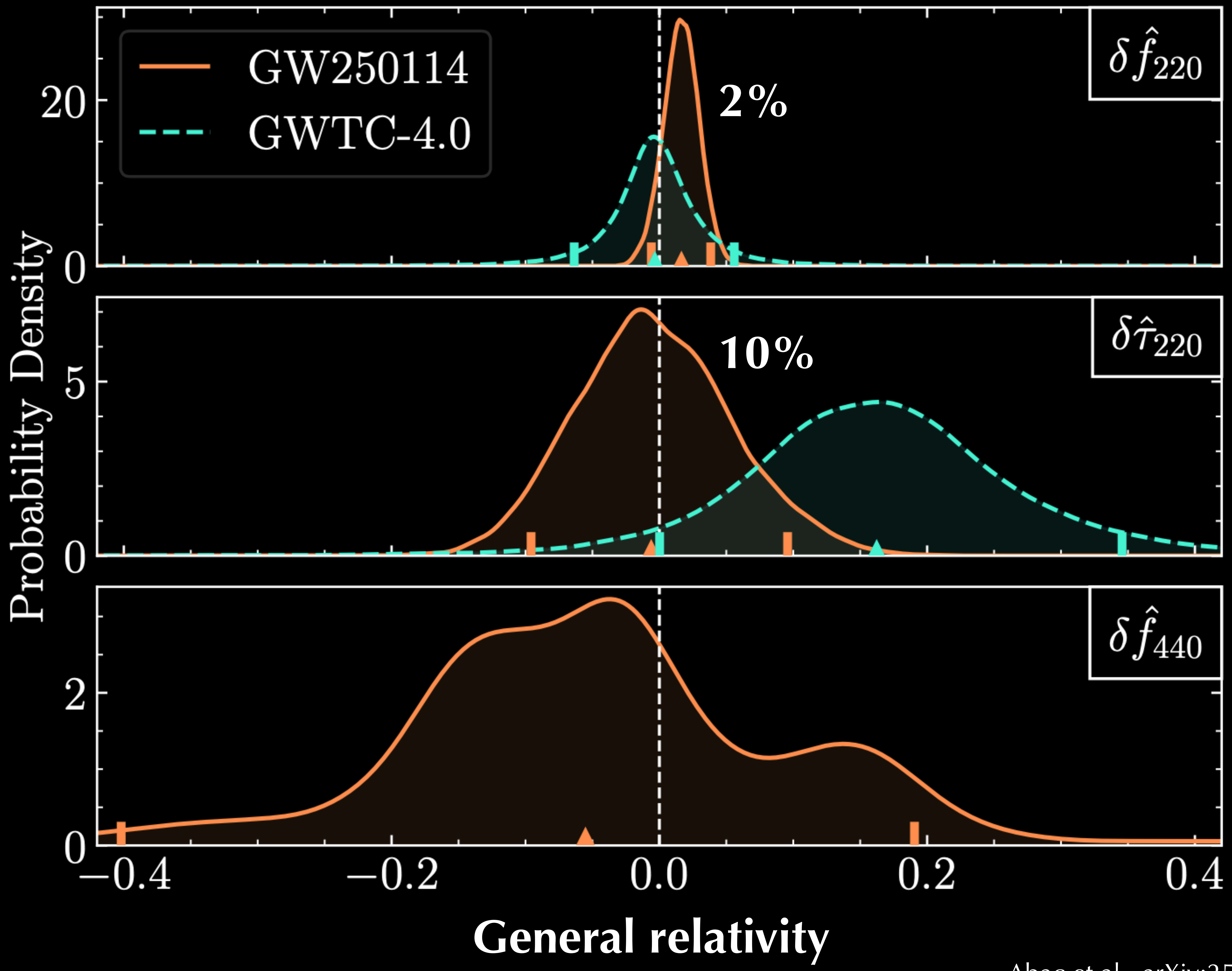
The ringdown of GW250114





https://ligo.org/science-summaries/GW250114_TGR/

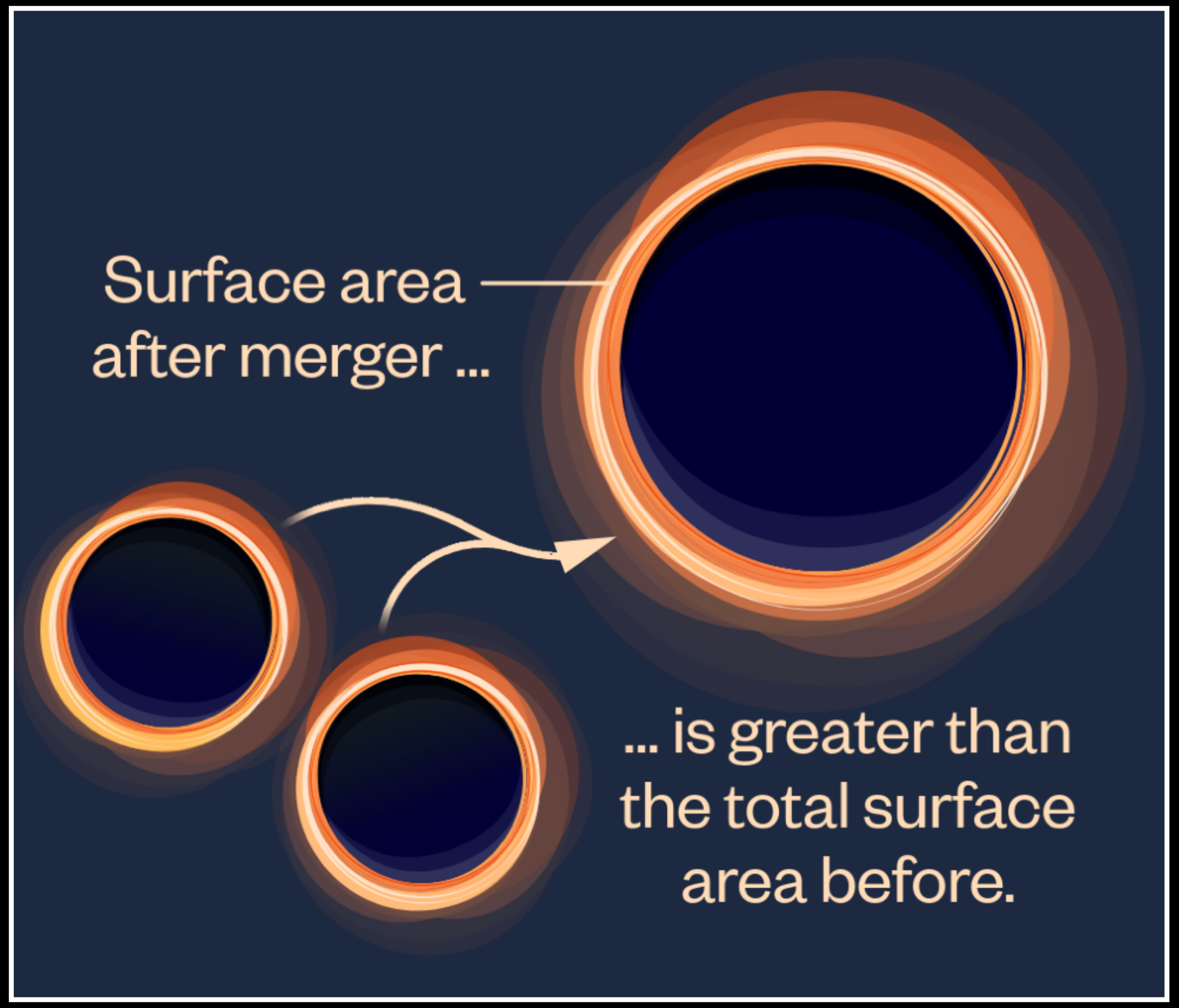
The ringdown of GW250114



Abac et al., arXiv:2509.08099

The fundamental mode is constrained twice as strictly as combining events from the fourth catalog.

Testing Hawking's area law

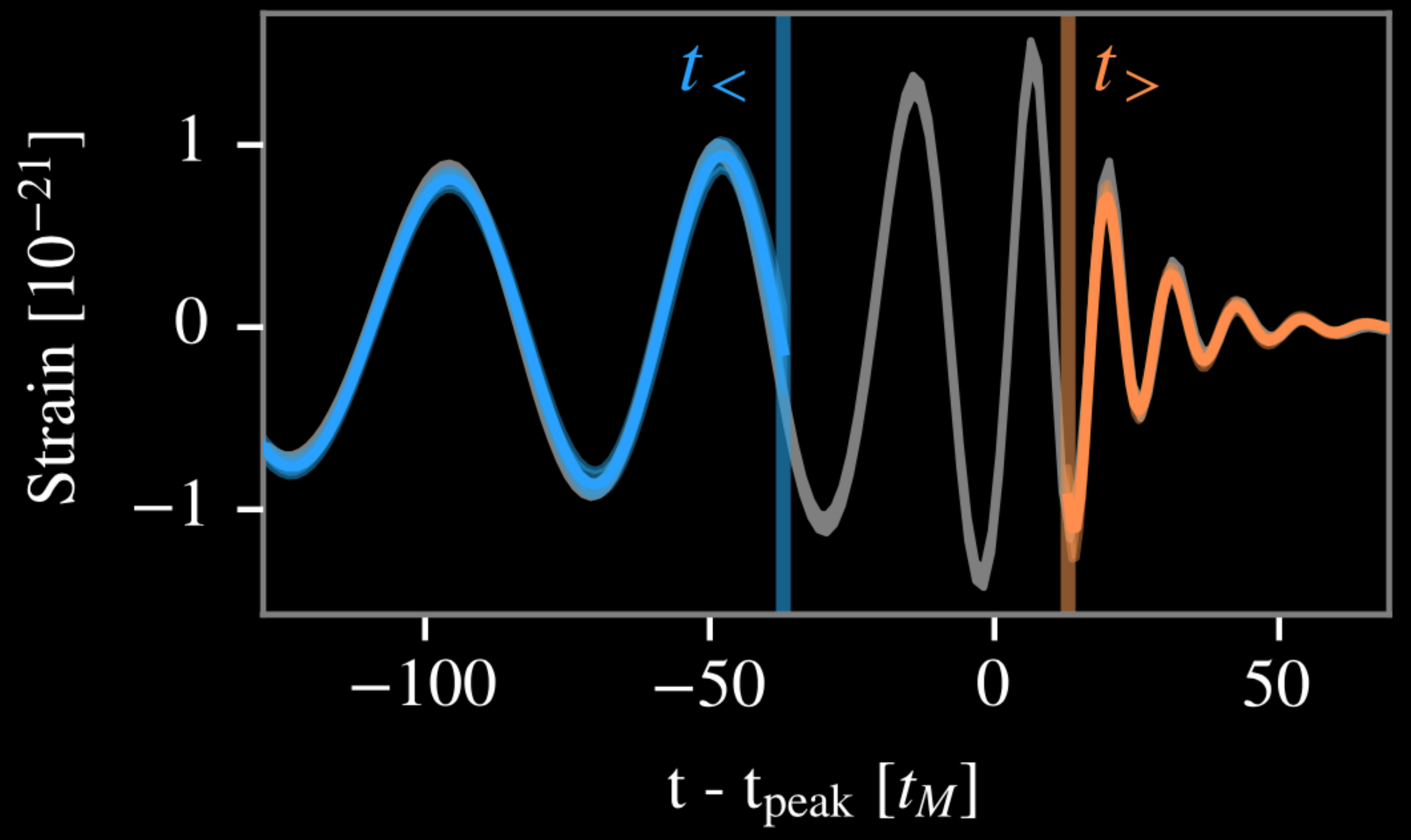


The black hole horizon area cannot decrease in time:

$$\mathcal{A} = 8\pi \left(\frac{GM}{c^2}\right)^2 \left(1 + \sqrt{1 - \chi^2}\right)$$

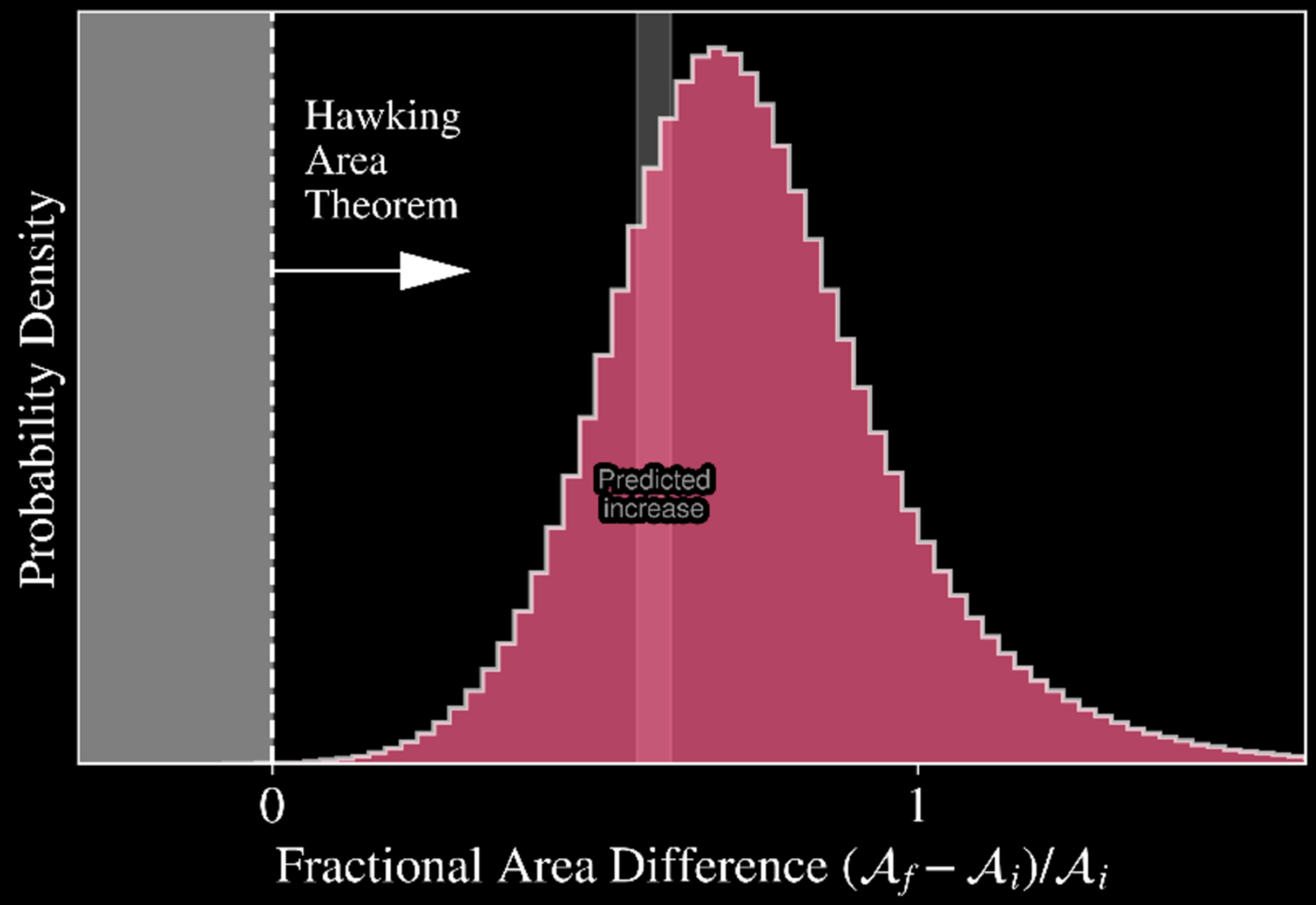
Mass Spin

We compare the areas of the black holes before and after the merger.



Testing Hawking's area law

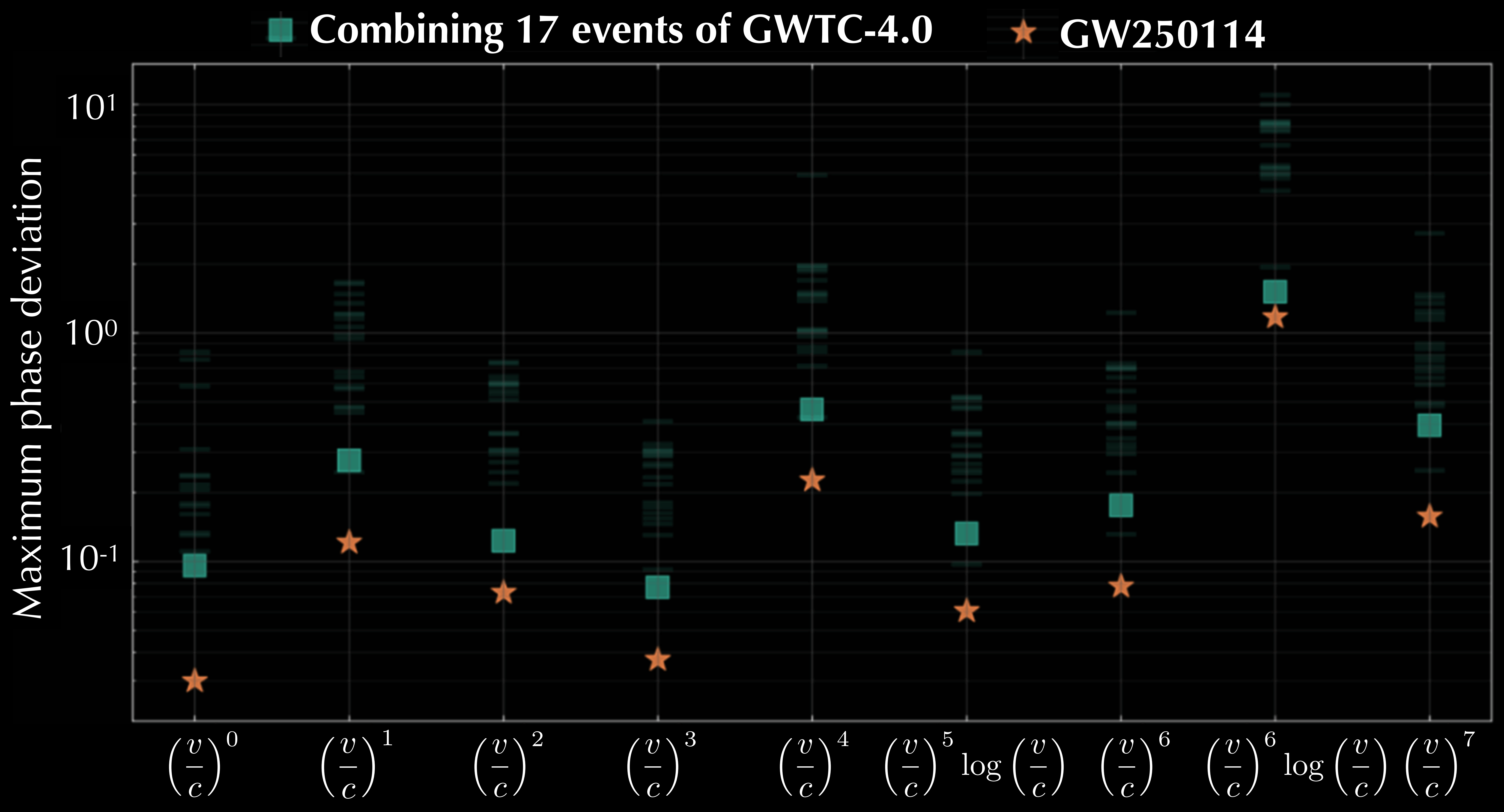
GW250114 confirms that the remnant area is larger than the sum of the initial areas.



Abac et al., PRL 135, 111403 (2025); https://ligo.org/science-summaries/gw250114_discovery/

The inspiral of GW250114

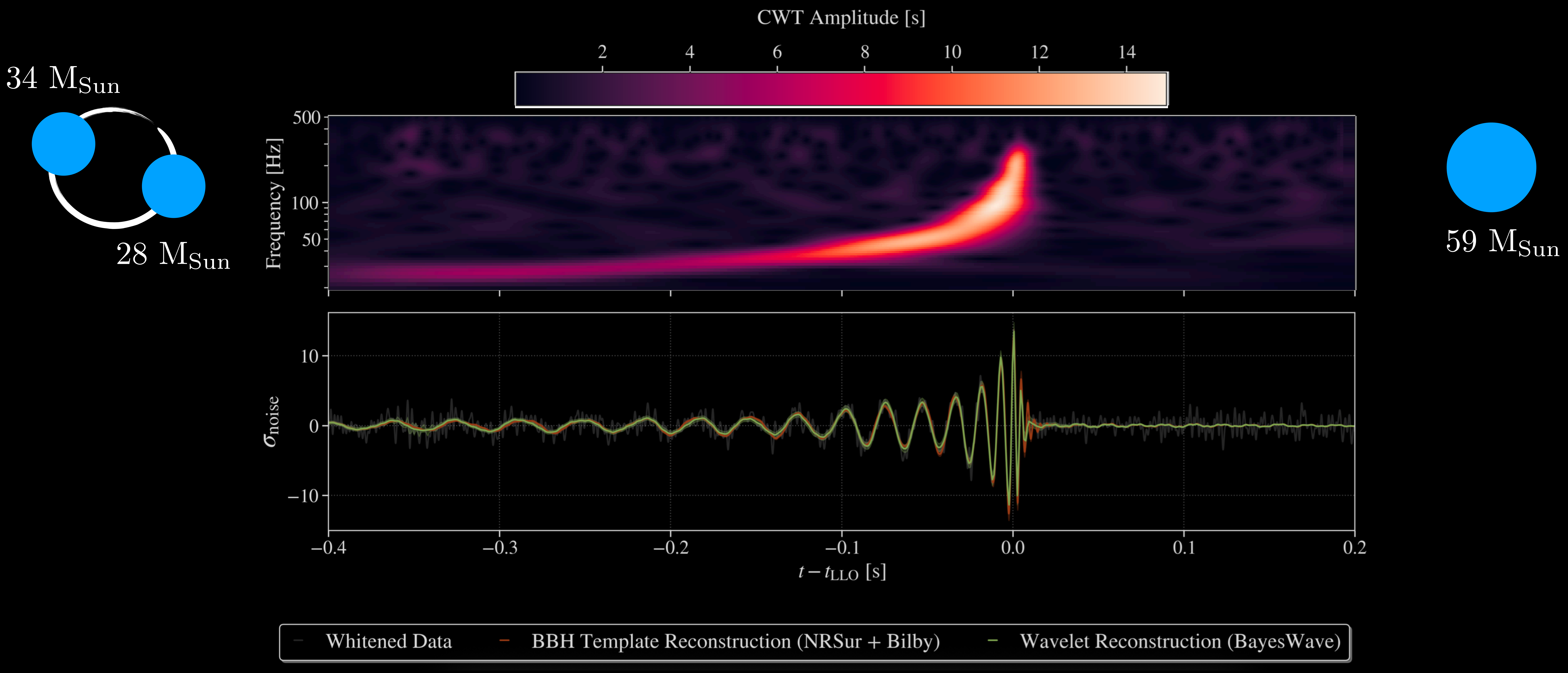
The inspiral can be treated perturbatively in the post-Newtonian framework in powers of v/c.



https://ligo.org/science-summaries/GW250114_TGR/

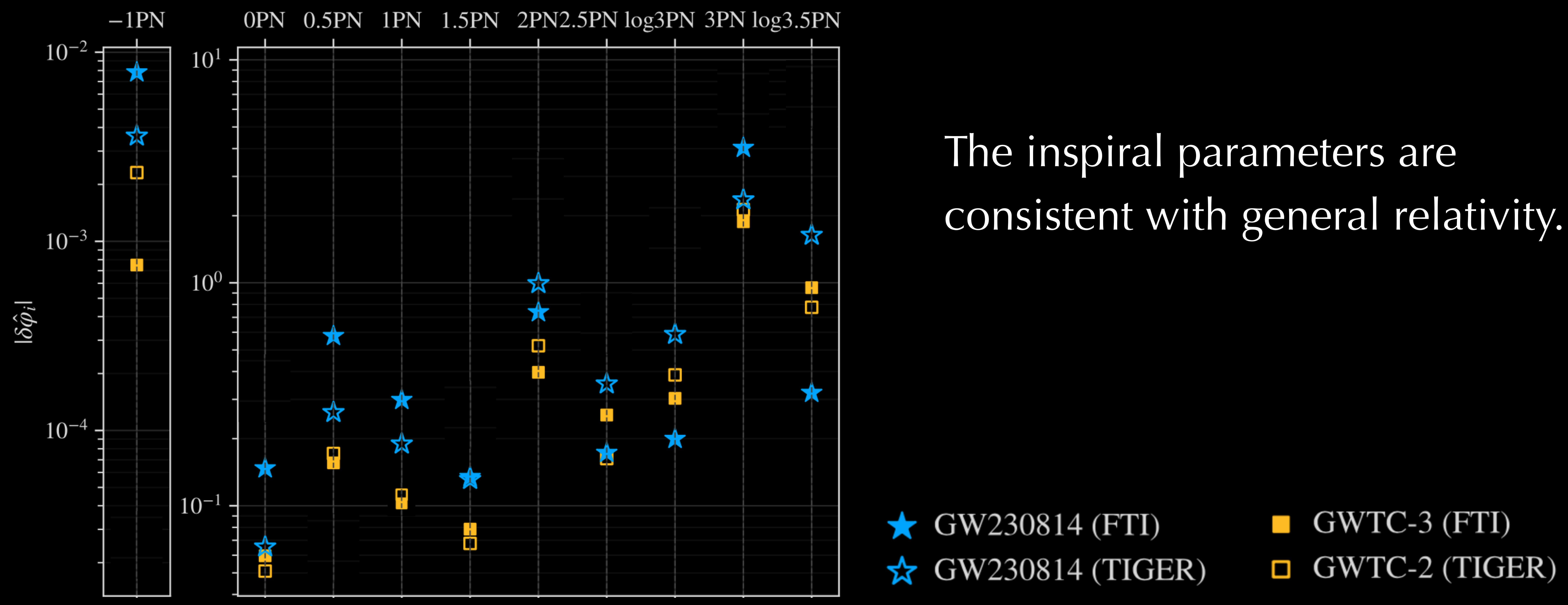
GW230814

The loudest gravitational-wave signal in the fourth catalog detected by LIGO Livingston, with signal-to-noise ratio of 42.4.



Abac et al., arXiv:2509.07348

The inspiral of GW230814



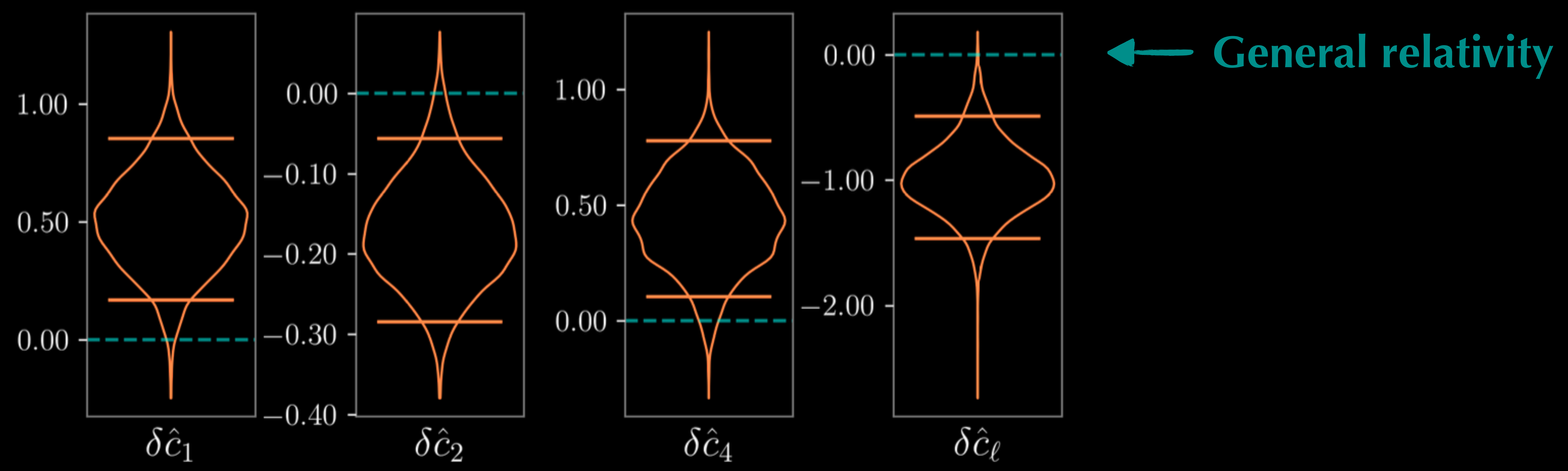
The inspiral parameters are consistent with general relativity.

Abac+, arXiv:2509.07348; Mehta+ 2023; Agathos+ 2024; Meidam+ 2018; Roy+ 2025

The merger-ringdown of GW230814

We constrain fractional deviations from general relativity in the merger-ringdown part.

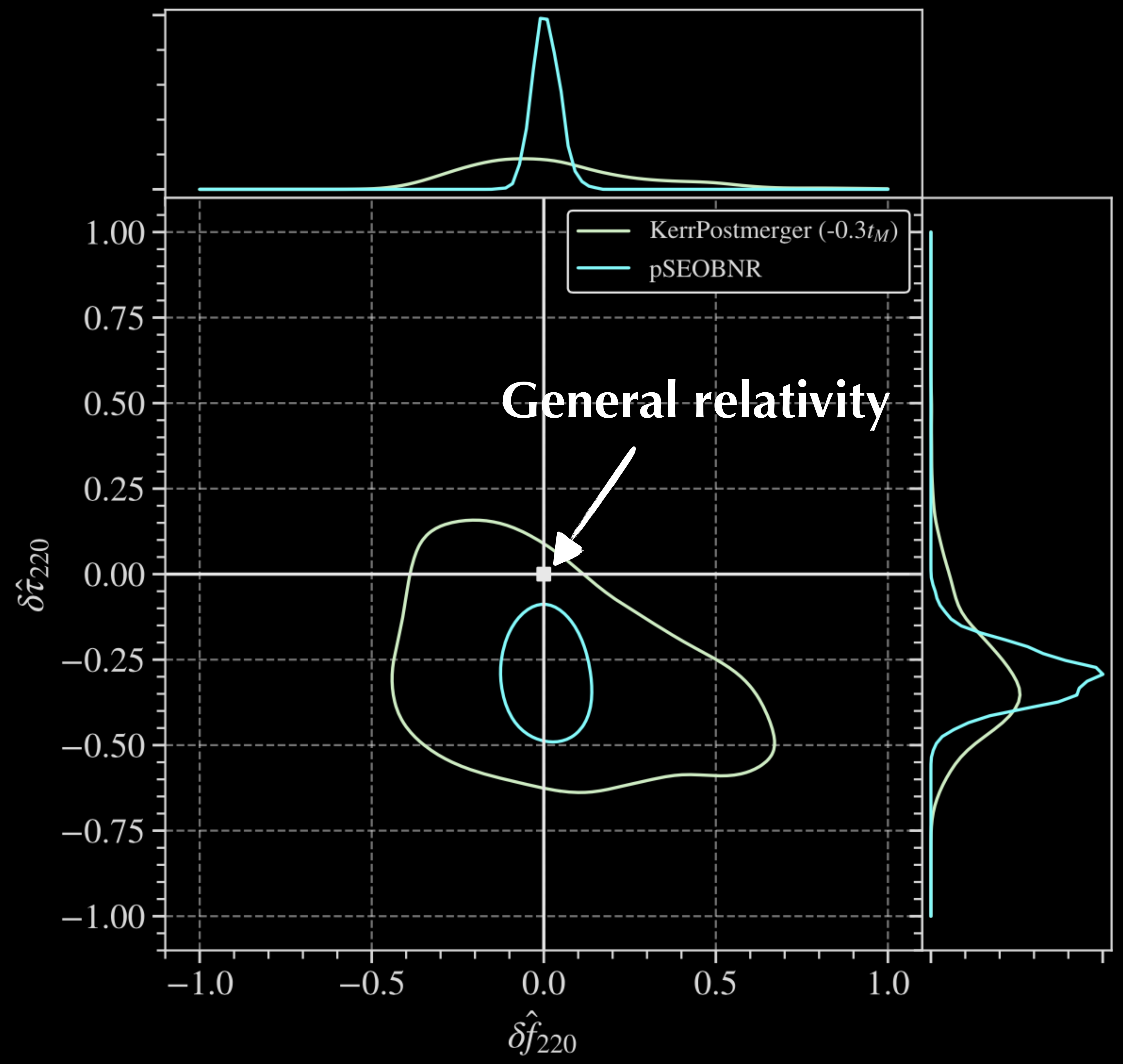
Merger-ringdown parameters



The posteriors are shifted from general relativity, with negative $\log_{10}$ Bayes factors.

Abac+, arXiv:2509.07348; Agathos+ 2024; Meidam+ 2018; Roy+ 2025

The ringdown of GW230814



The data supports a damping time smaller than expected from general relativity:

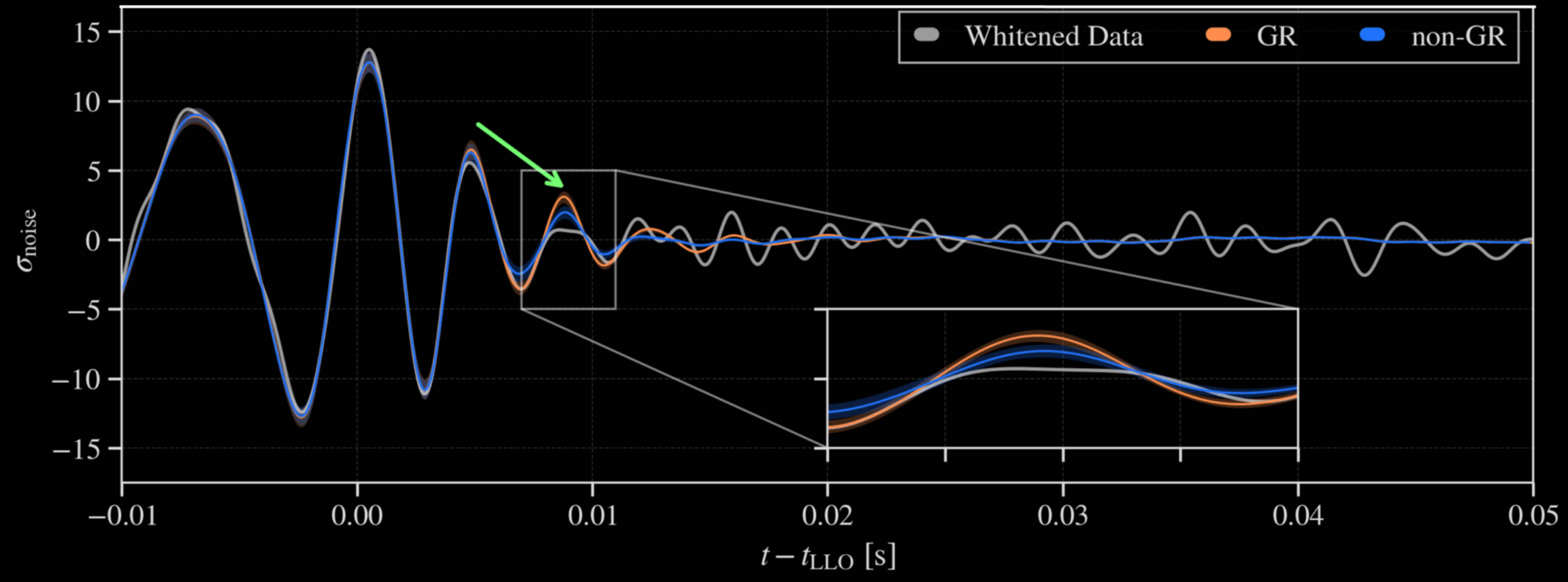
$$\delta\hat{\tau}_{220} = -0.3^{+0.15}_{-0.12}$$

The $\log_{10}$ Bayes factor is -0.43.

Abac+, arXiv:2509.07348; Brito+ 2018; Ghosh+ 2021; Maggio+ 2023; Pompili+ 2025; Carullo+ 2019; Isi+ 2021; Gennari+ 2024

The ringdown of GW230814

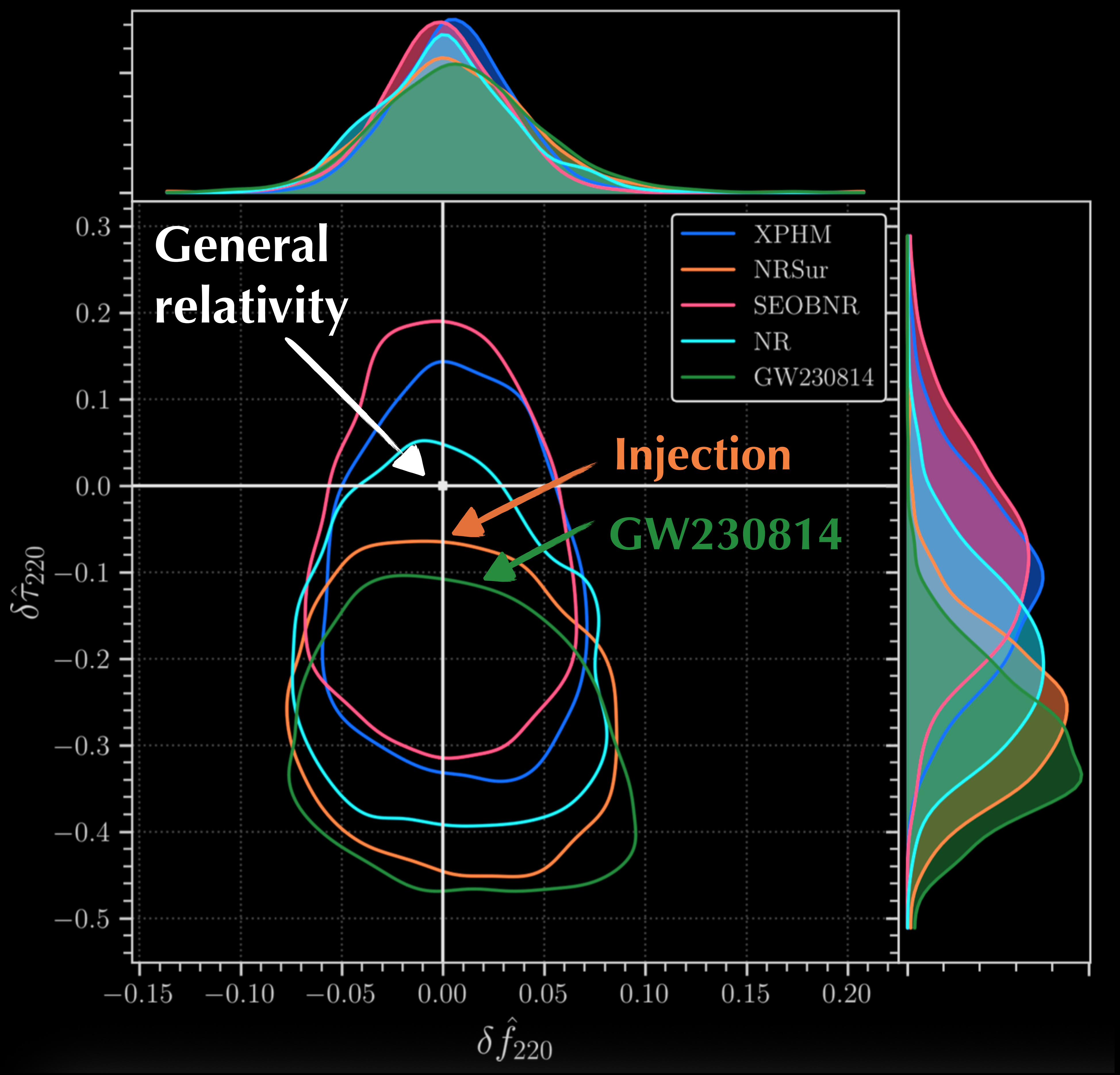
The ringdown analysis provides a visibly better fit to the data. *What causes this deviation?*



https://ligo.org/science-summaries/GW230814/

Assessing waveform systematics

We perform injections with different waveform models in zero noise.

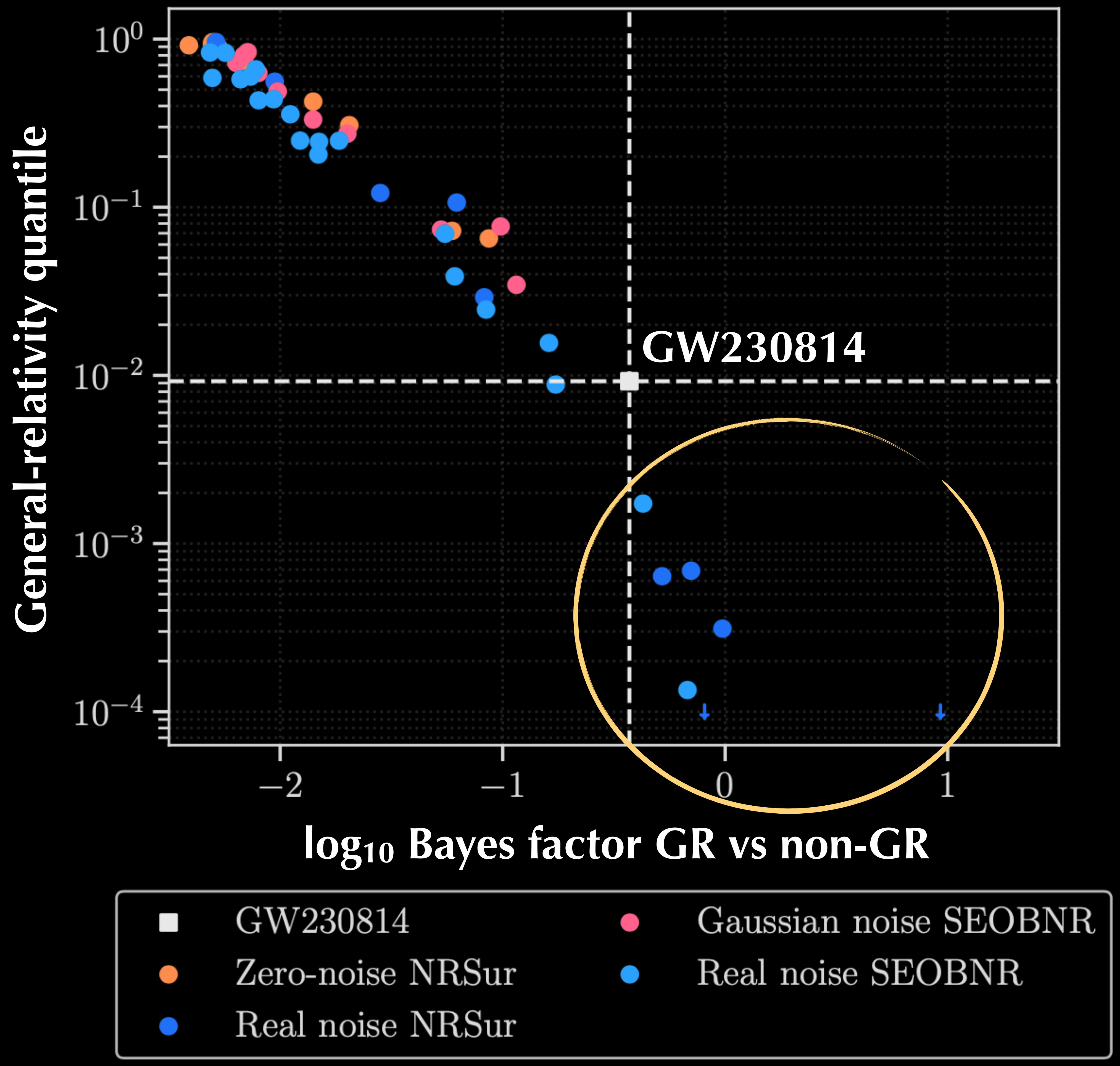


Waveform systematics could contribute to the observed bias in the ringdown damping time.

Abac et al., arXiv:2509.07348107

Assessing detector effects

We perform injections in the real noise of the detector at various times around the event.

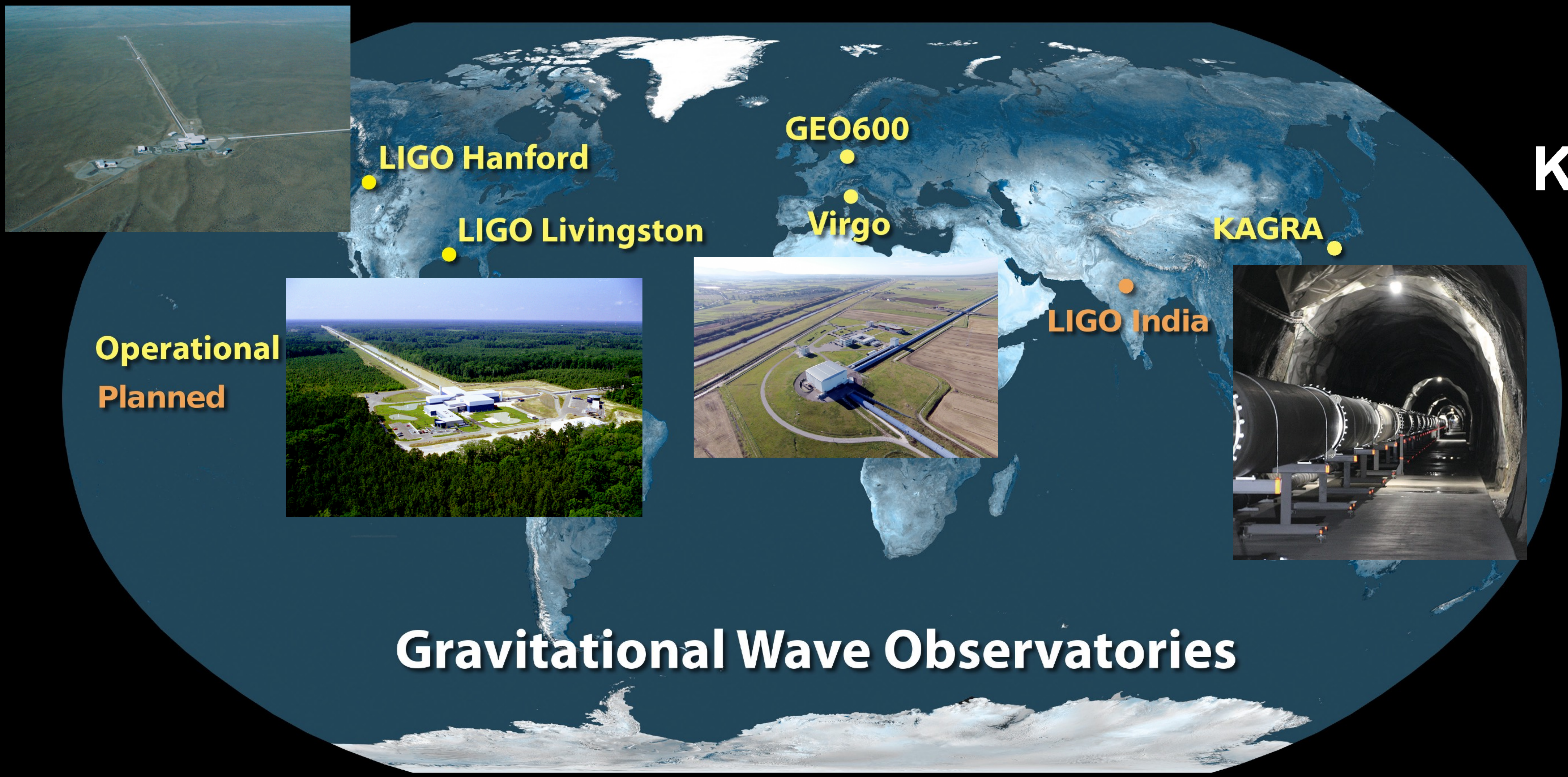


Statistical fluctuations in real detector noise can be responsible for apparent deviations from general relativity in the ringdown.

Abac et al., arXiv:2509.07348107

The importance of a detector network

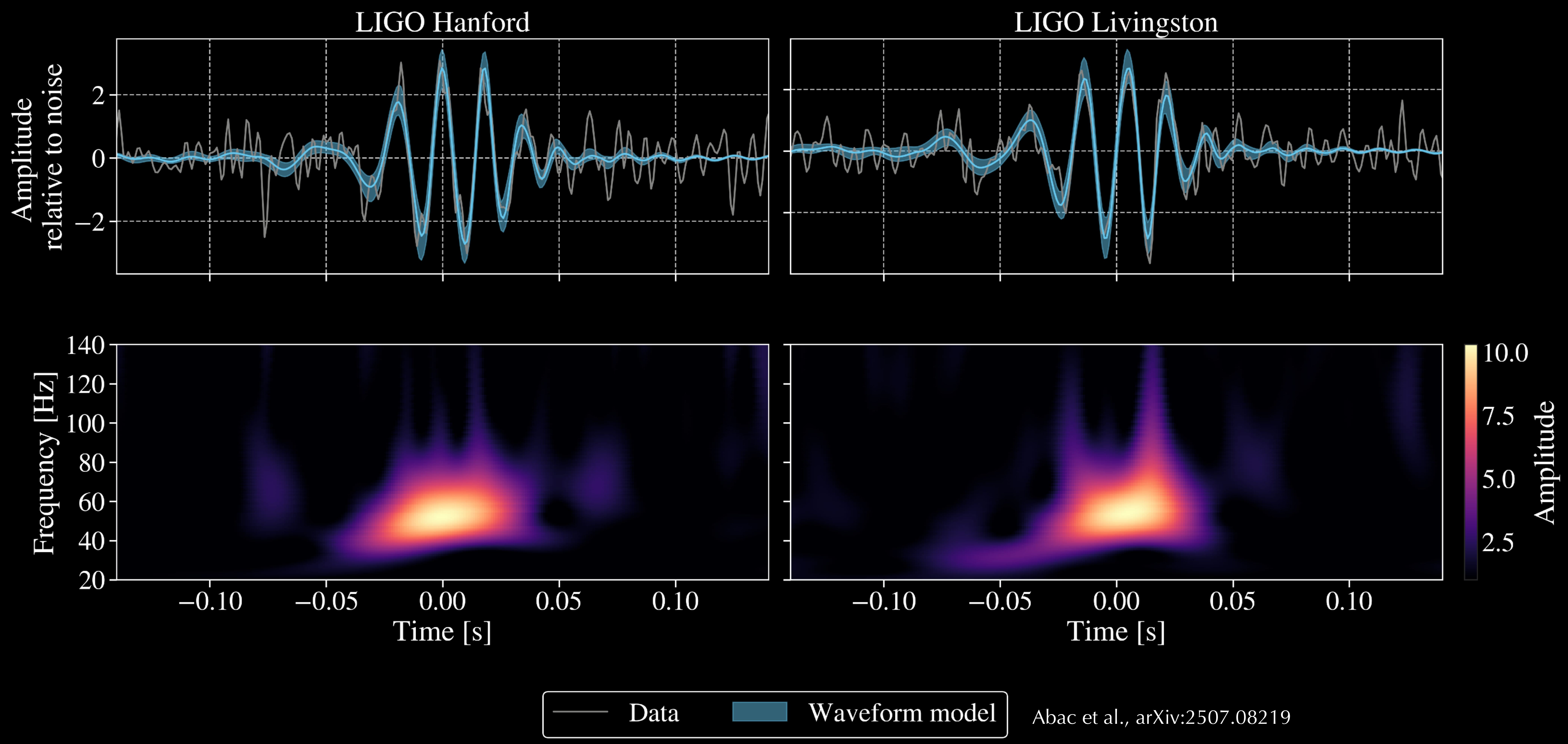
GW230814 highlights the need for a global network of gravitational-wave observatories for robust tests of fundamental physics.



Credit:Caltech/MIT/LIGO Lab; EGO/Virgo; ICRR; GEO600

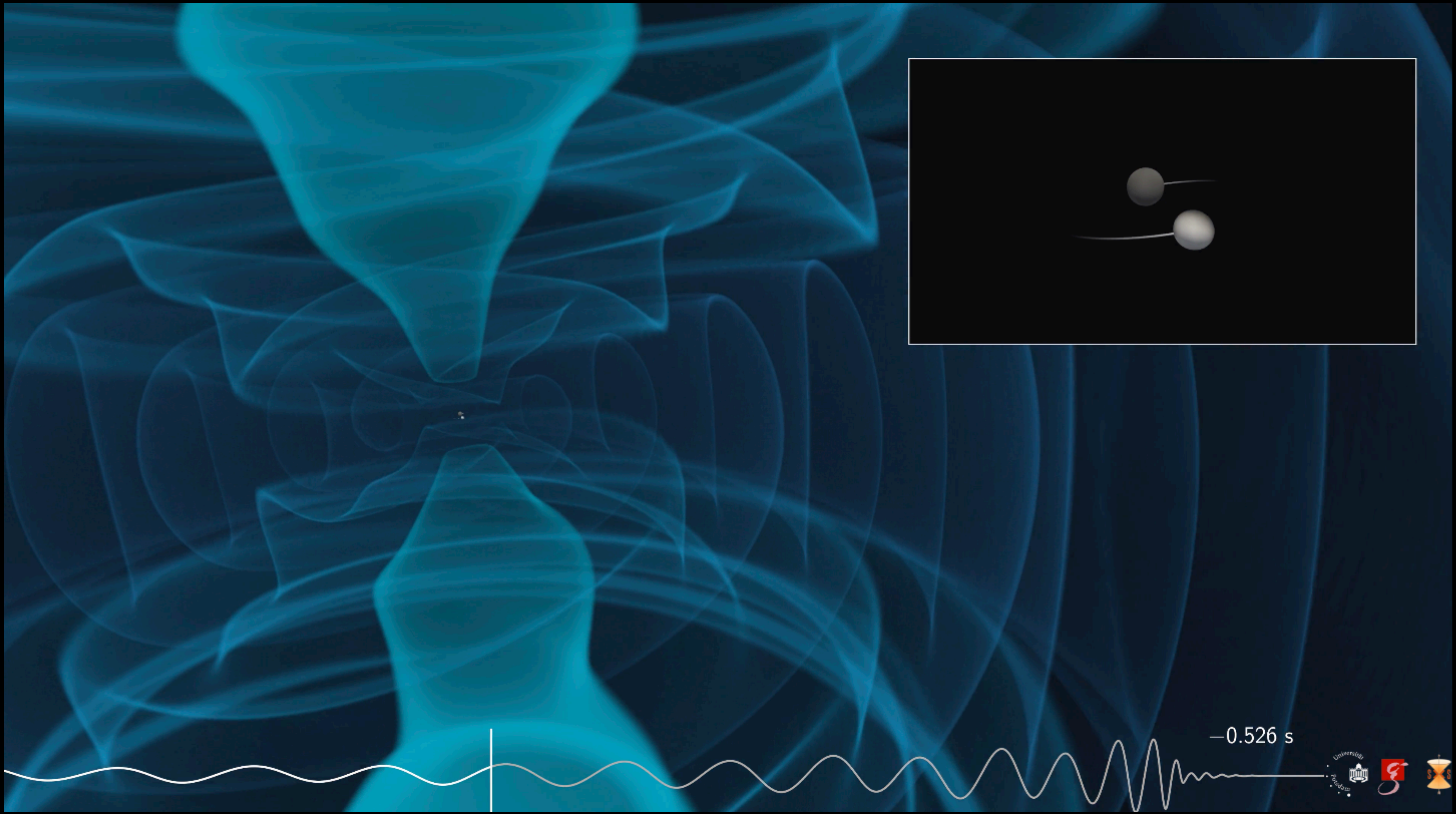
GW231123

A gravitational wave signal from the most massive binary black hole observed to date



Abac et al., arXiv:2507.08219

GW231123

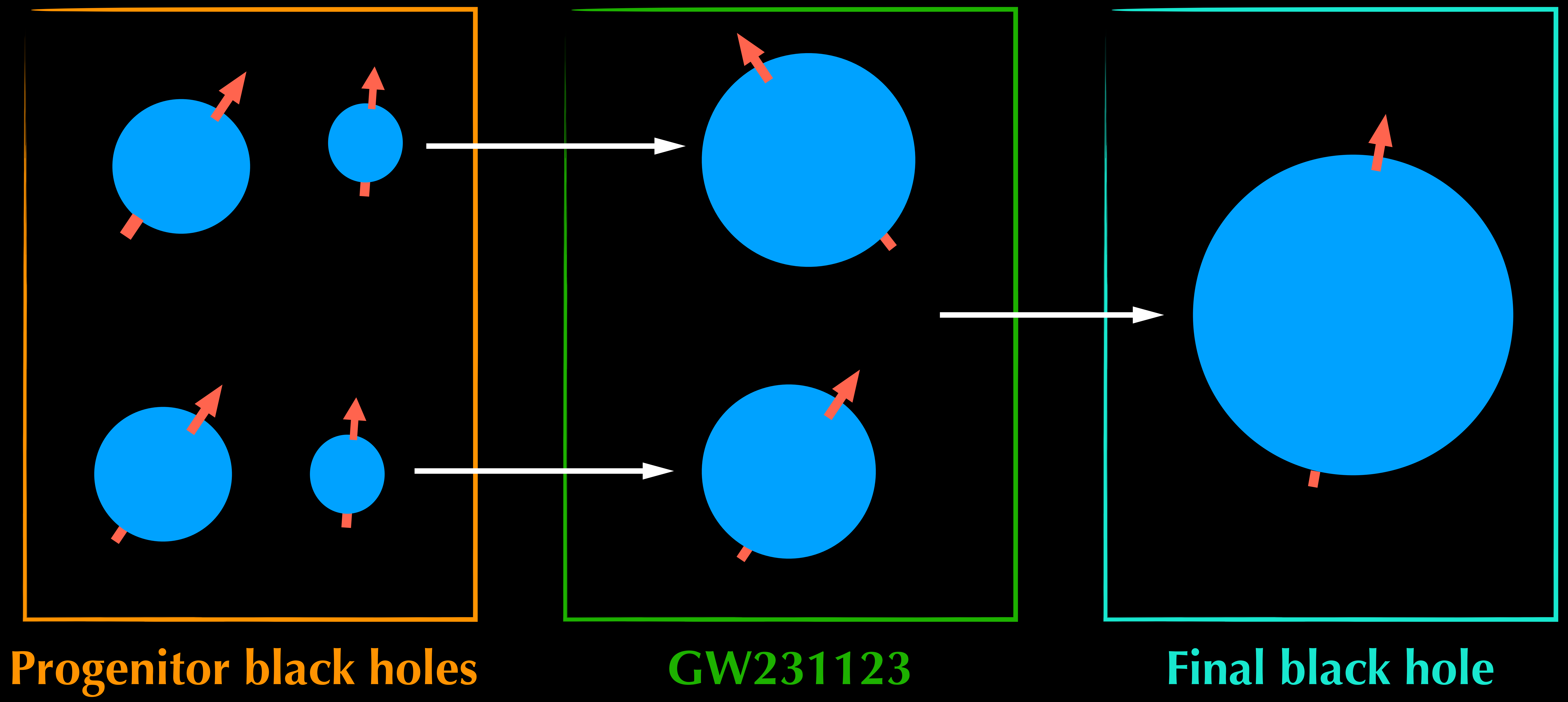


$140 + 100 \rightarrow 225\ M_{\text{Sun}}$

15 Solar masses emitted in gravitational waves in only 0.1s

GW231123

GW231123 hints at black holes formed through multiple generations of mergers



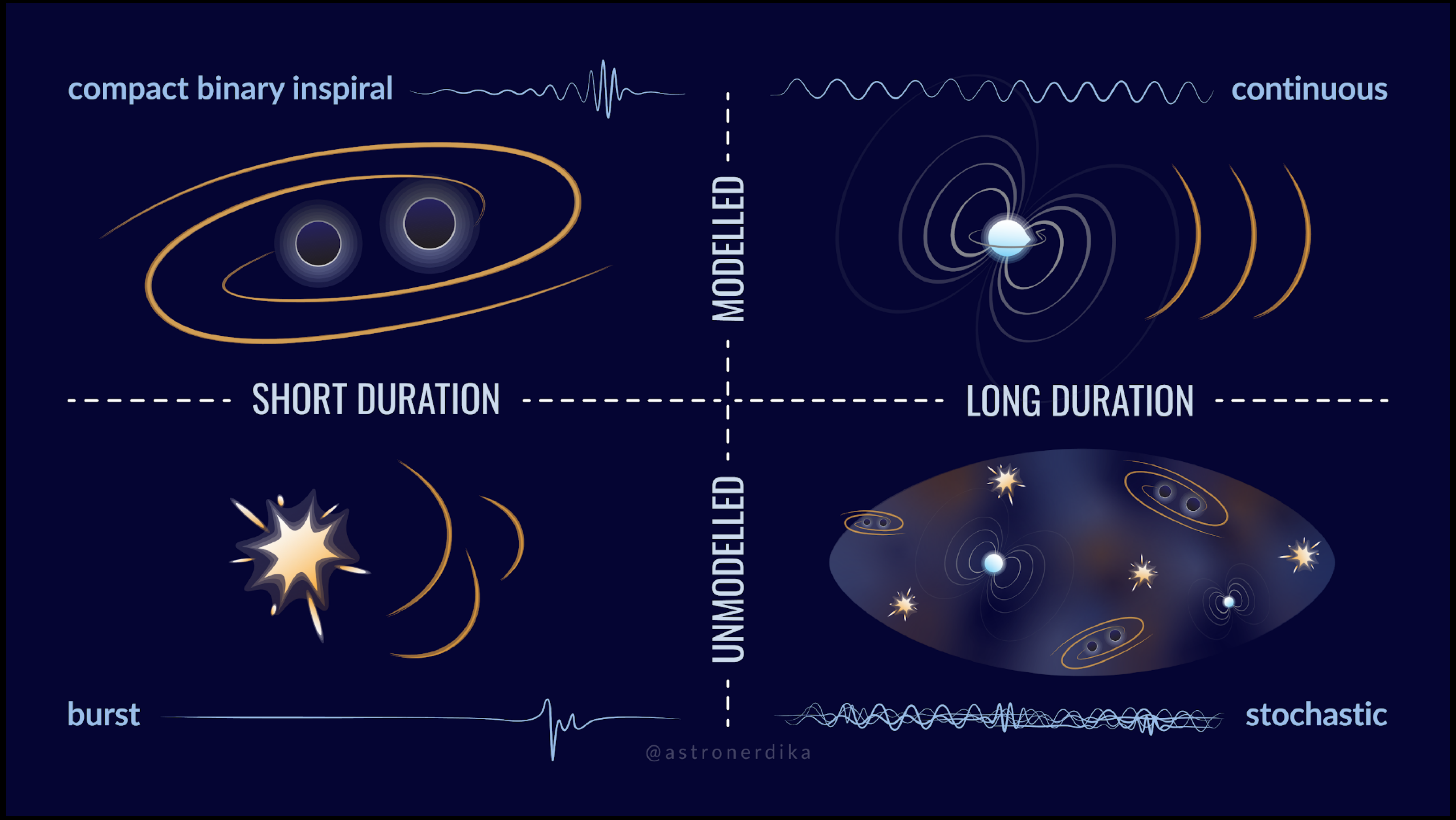
Credit: L. Pompili

Conclusions

10 years from the first detection, we have observed:

- The birth of multimessenger astronomy and cosmology
- A population of massive and spinning black holes
- The existence of compact objects in the mass gaps
- Tests of the nature of black holes

What will happen in the next 10 years?



https://shanikagalaudage.github.io/