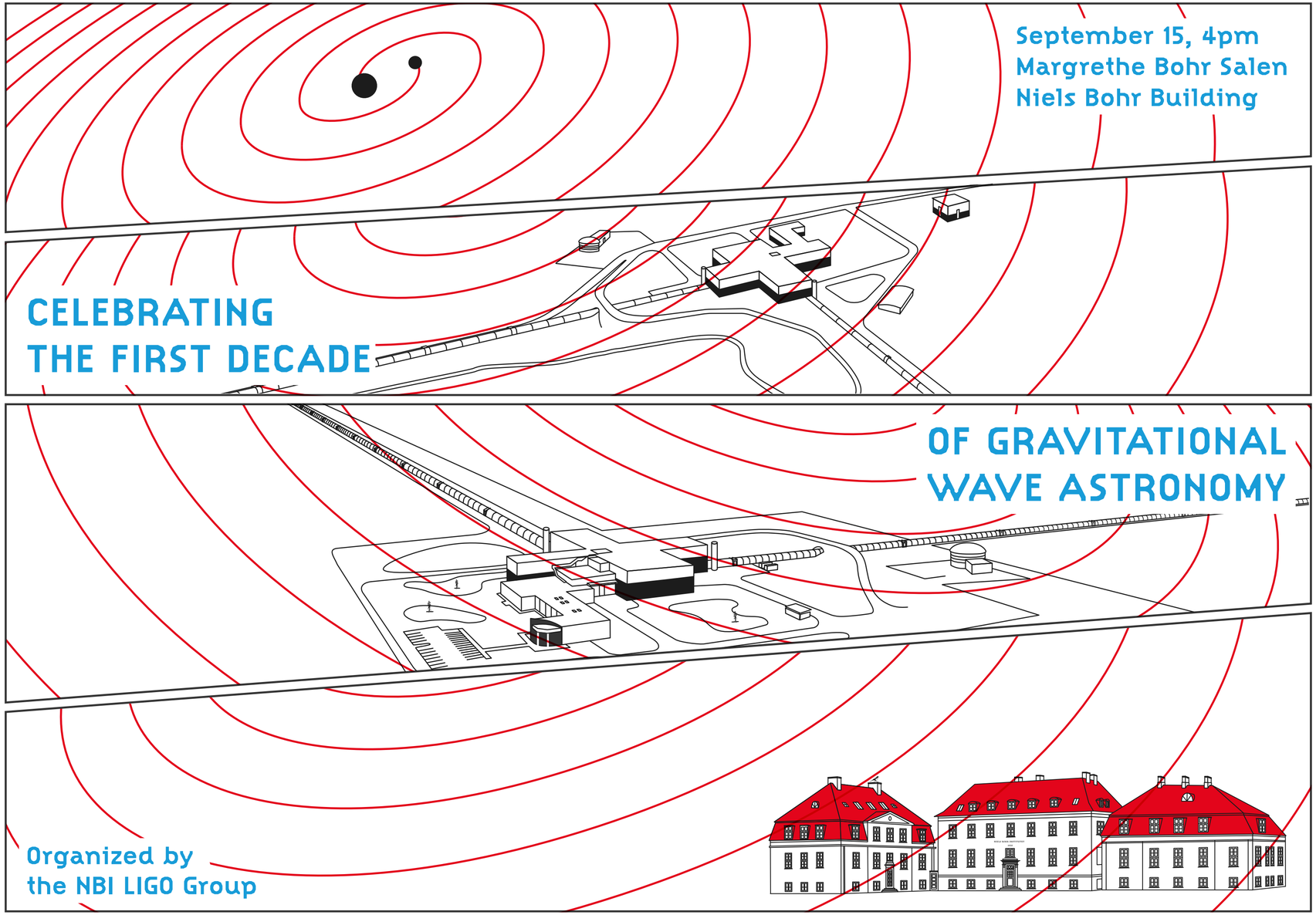


LSC LIGO Scientific Collaboration

VILLUM FONDEN

KØBENHAVNS UNIVERSITET

THE CENTER OF GRAVITY

NBI LIGO group


Joey Bowman


Juno Chan


Jose M. Ezquiaga


Asta Heinesen

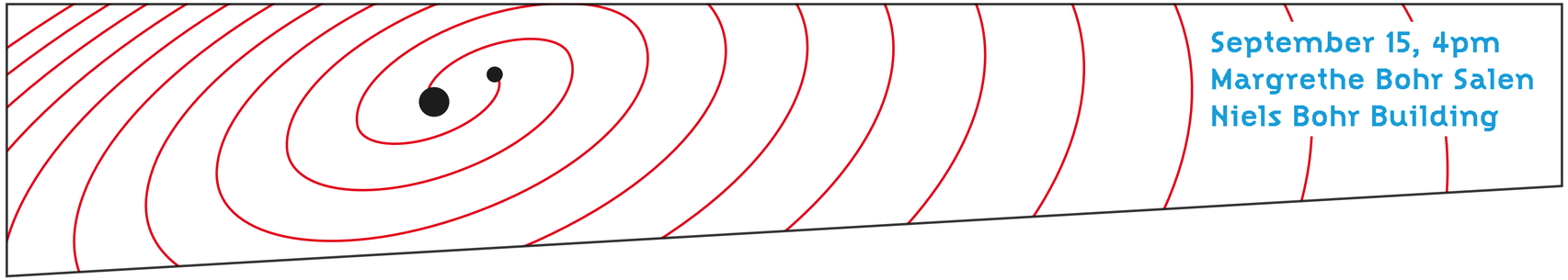

Rico Lo

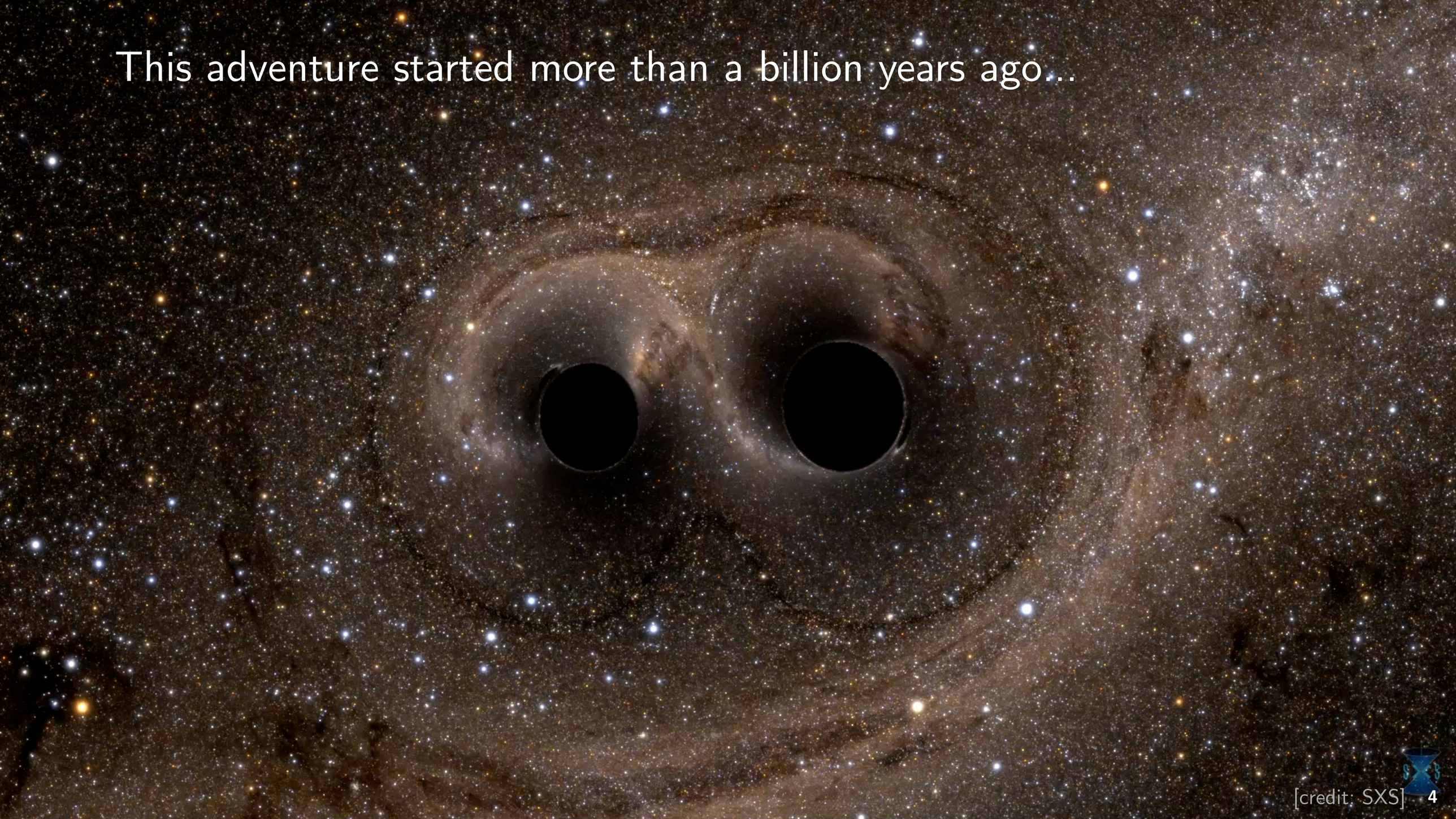

Lorena Magaña


Simon Maenaut


Luka Vujeva

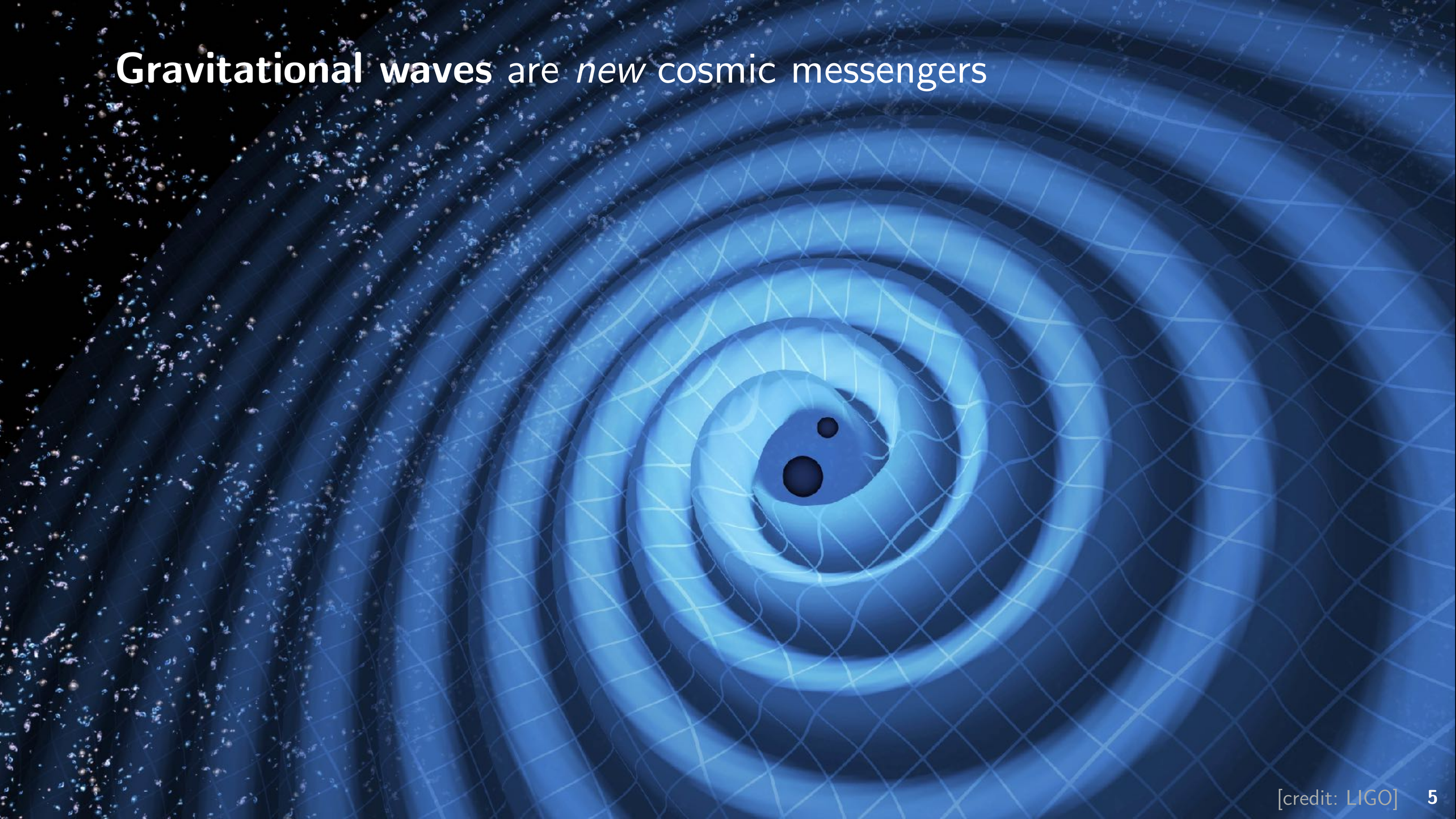
[https://ezquiaga.github.io/group.html]


September 15, 4pm
Margrethe Bohr Salen
Niels Bohr Building



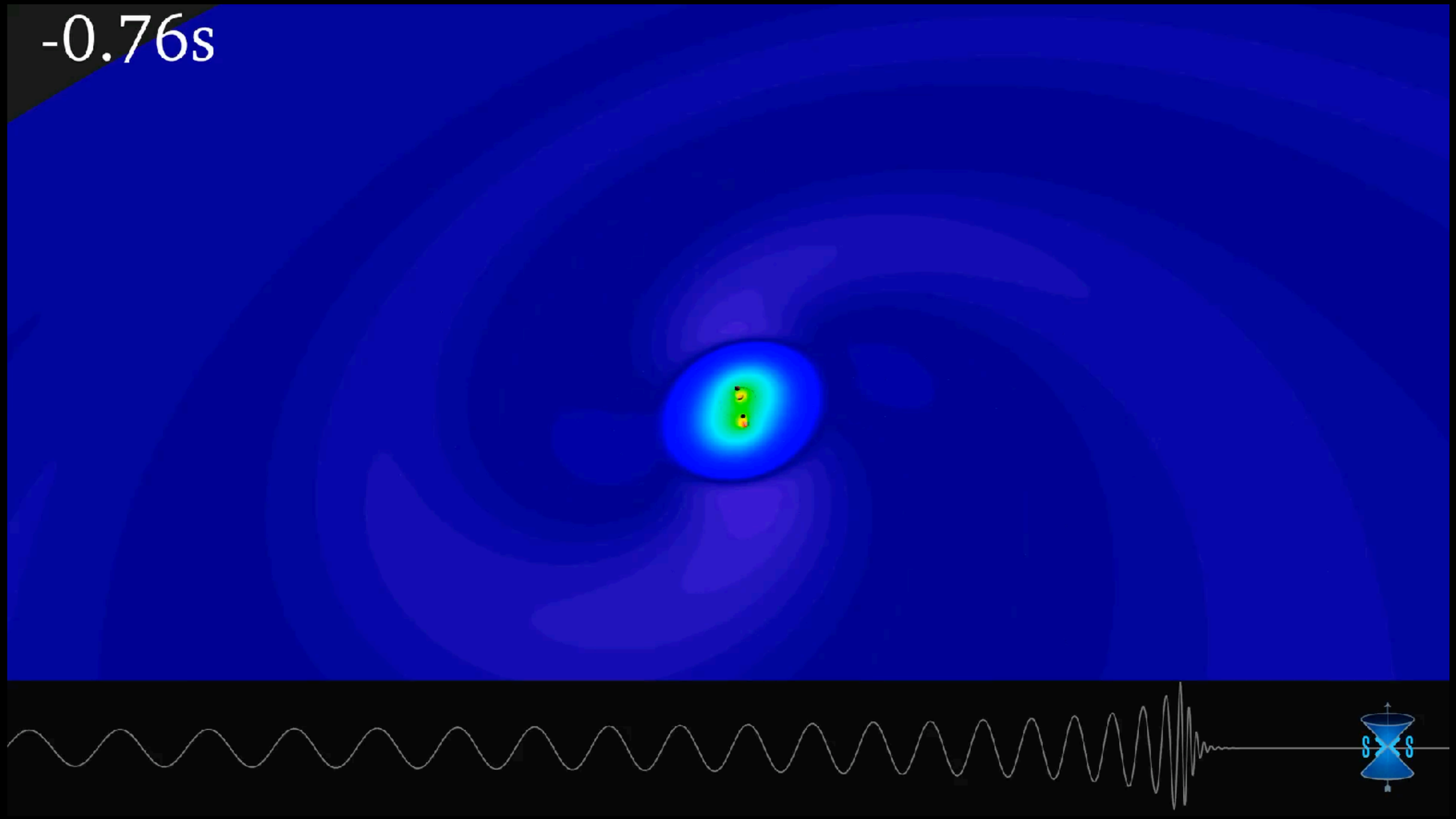
[credit: SXS]

Gravitational waves are *new* cosmic messengers



[credit: LIGO]

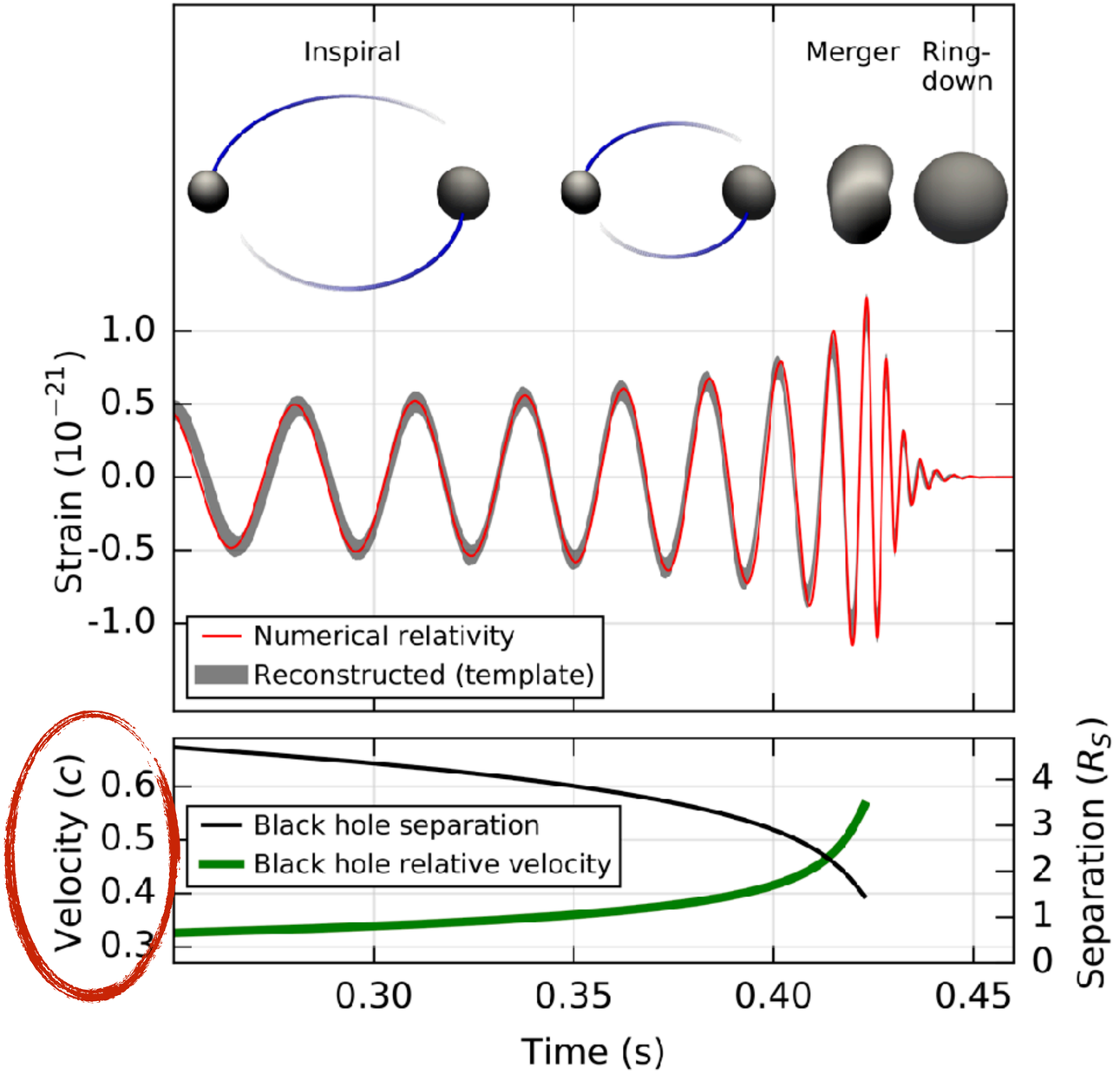
Numerical simulation of a binary black hole merger



[Credit: SXS]

Gravitational waves from stellar-mass **binary black holes**

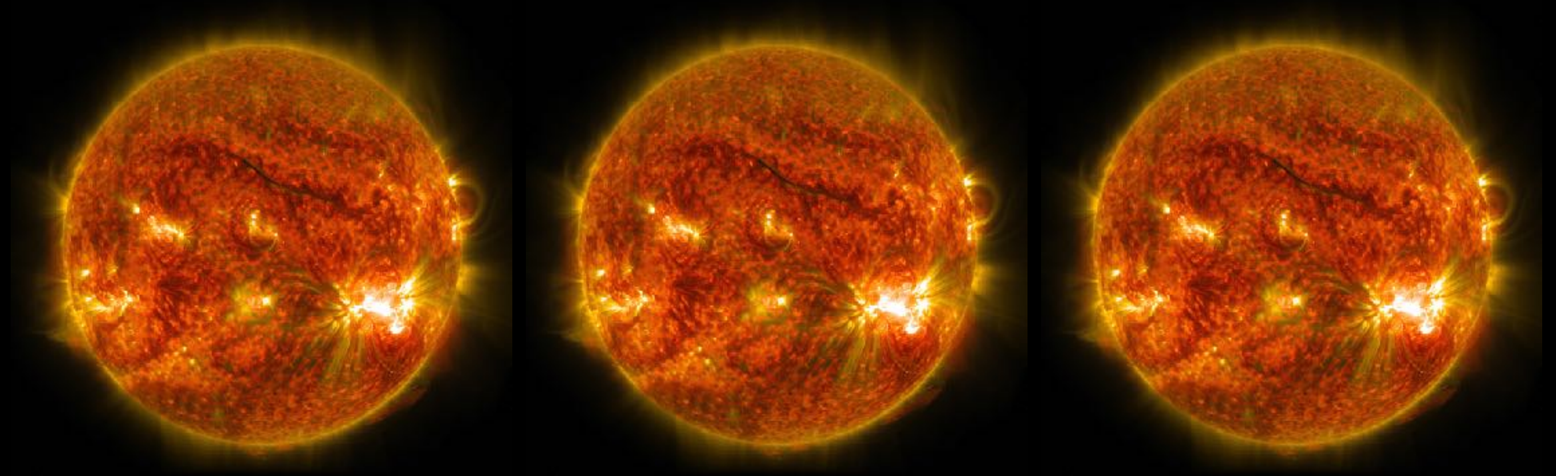
Strong-field gravity



[First detection, GW150914]

Energy emitted in gravitational waves

=



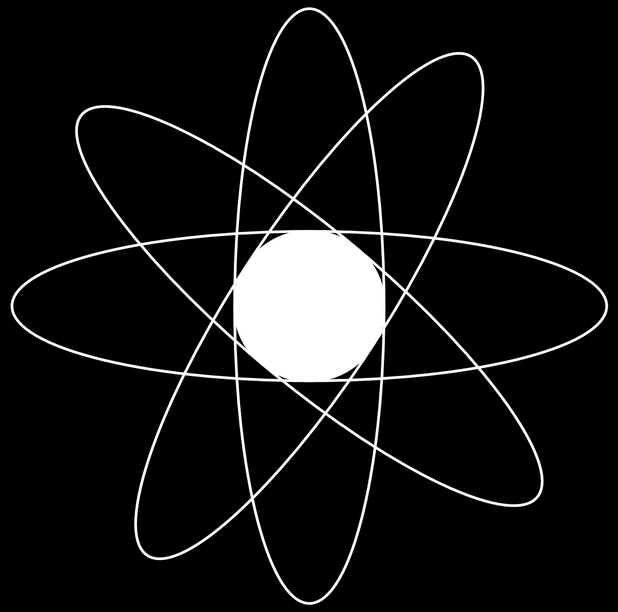
>

How large is the effect?

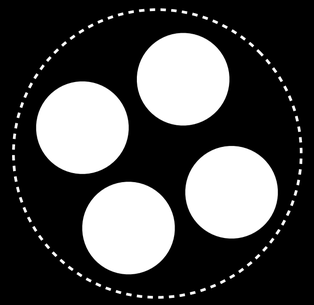
[Credit: R. Hurt, Caltech/MIT/LIGO Lab]

The variation in the distance at the detector is minuscule

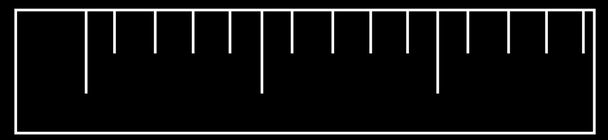
0.00000000000000001 meters



atom: 10^{-10} meters

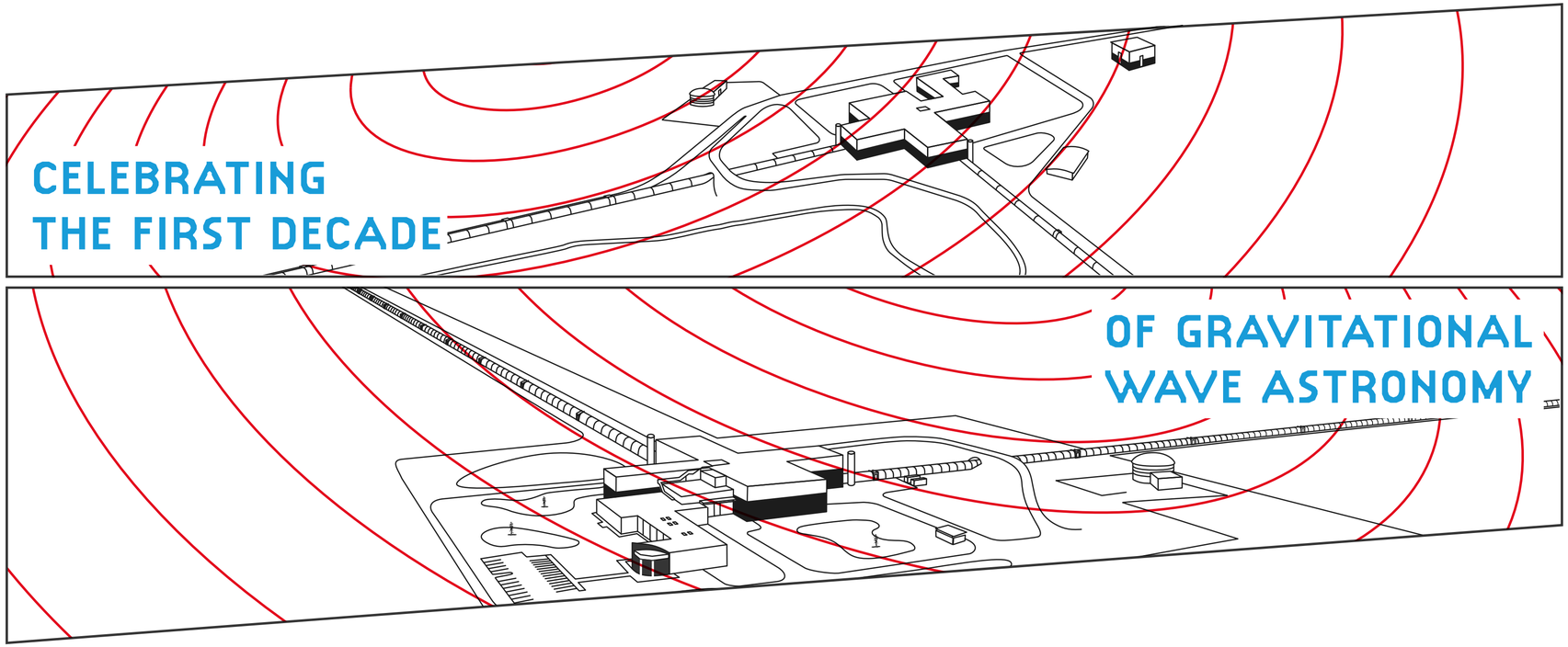


nucleus: 10^{-15} meters

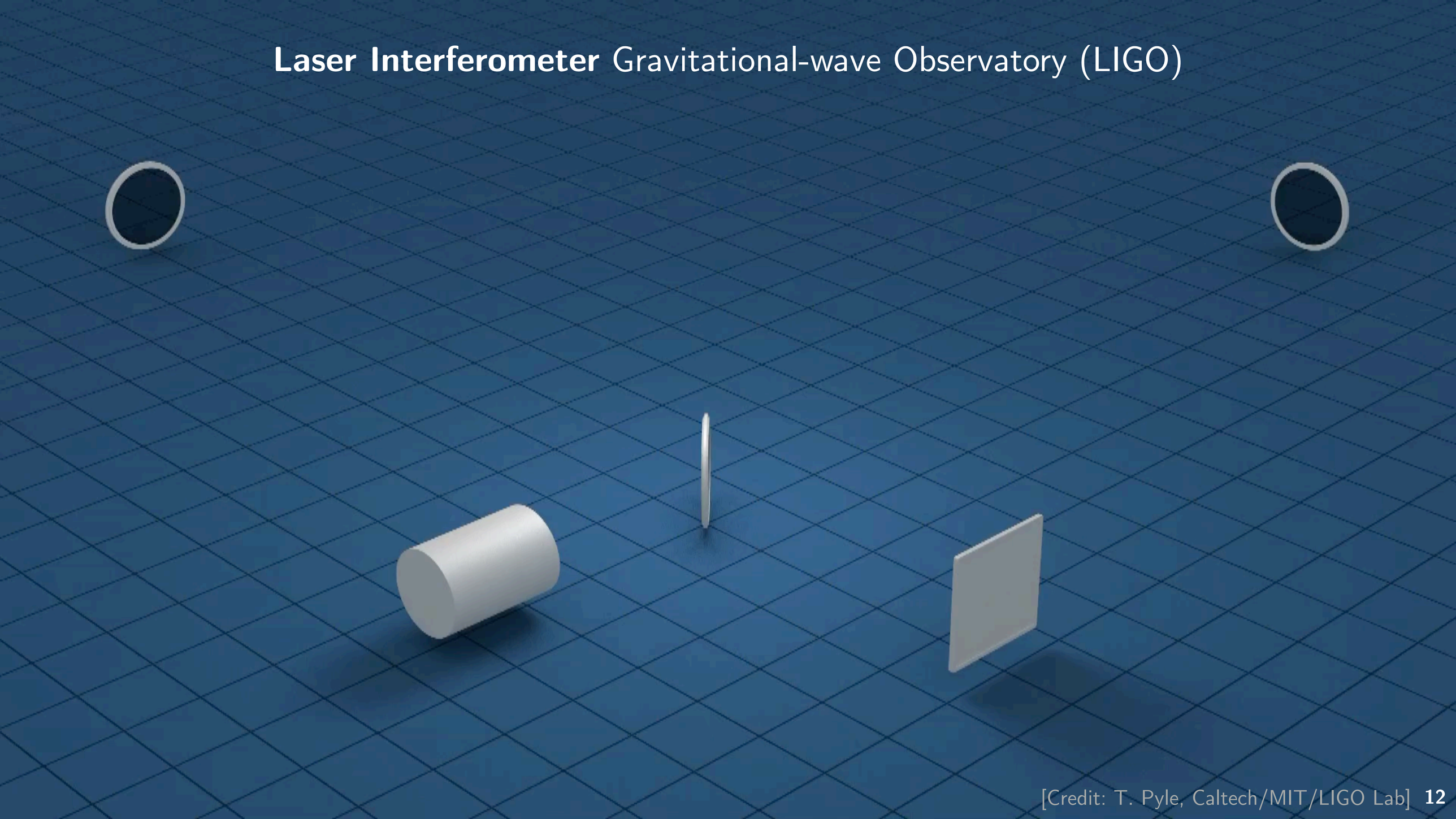


GW effect: 10^{-18} meters

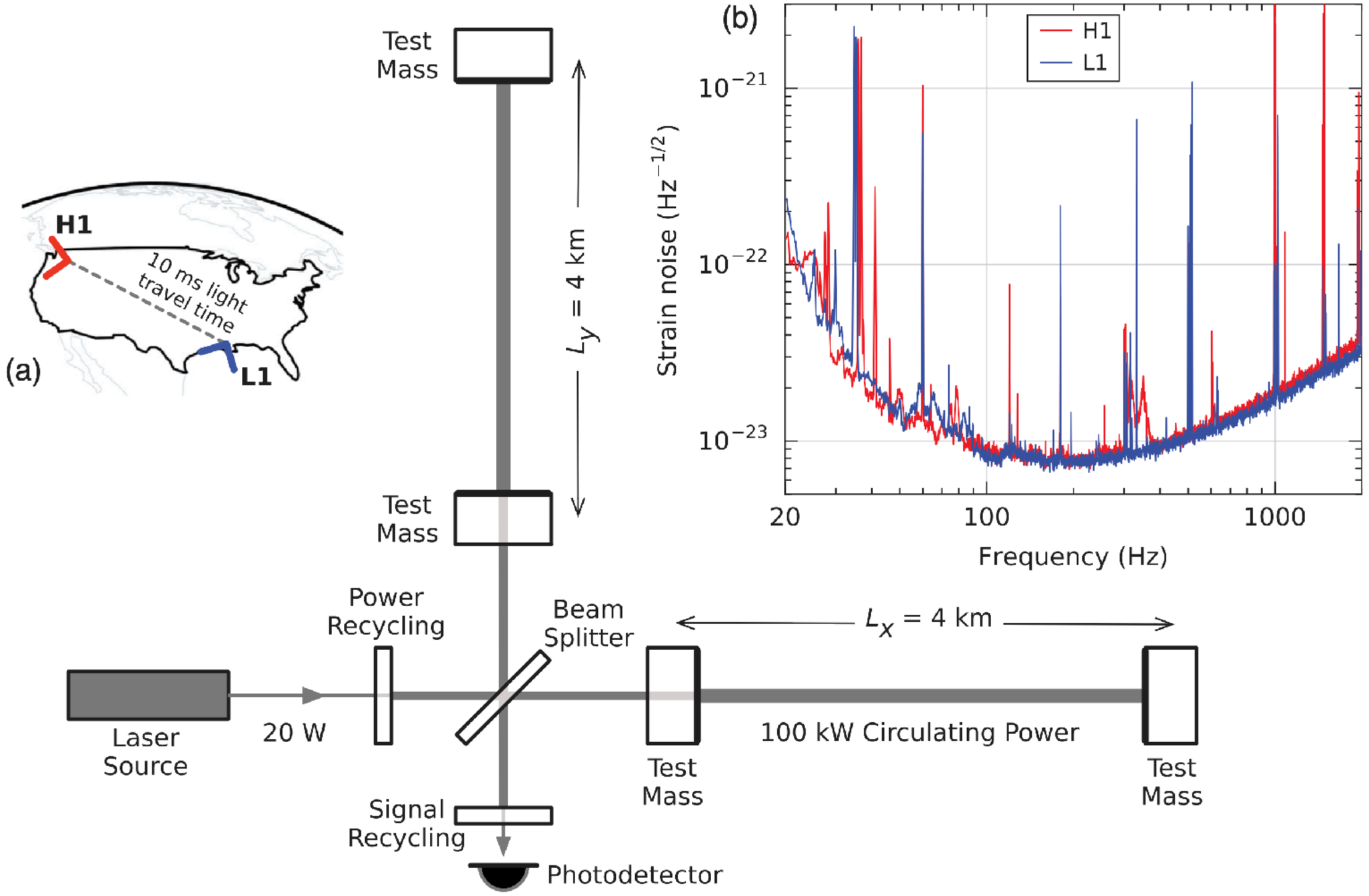
CELEBRATING THE FIRST DECADE OF GRAVITATIONAL WAVE ASTRONOMY



Laser Interferometer Gravitational-wave Observatory (LIGO)

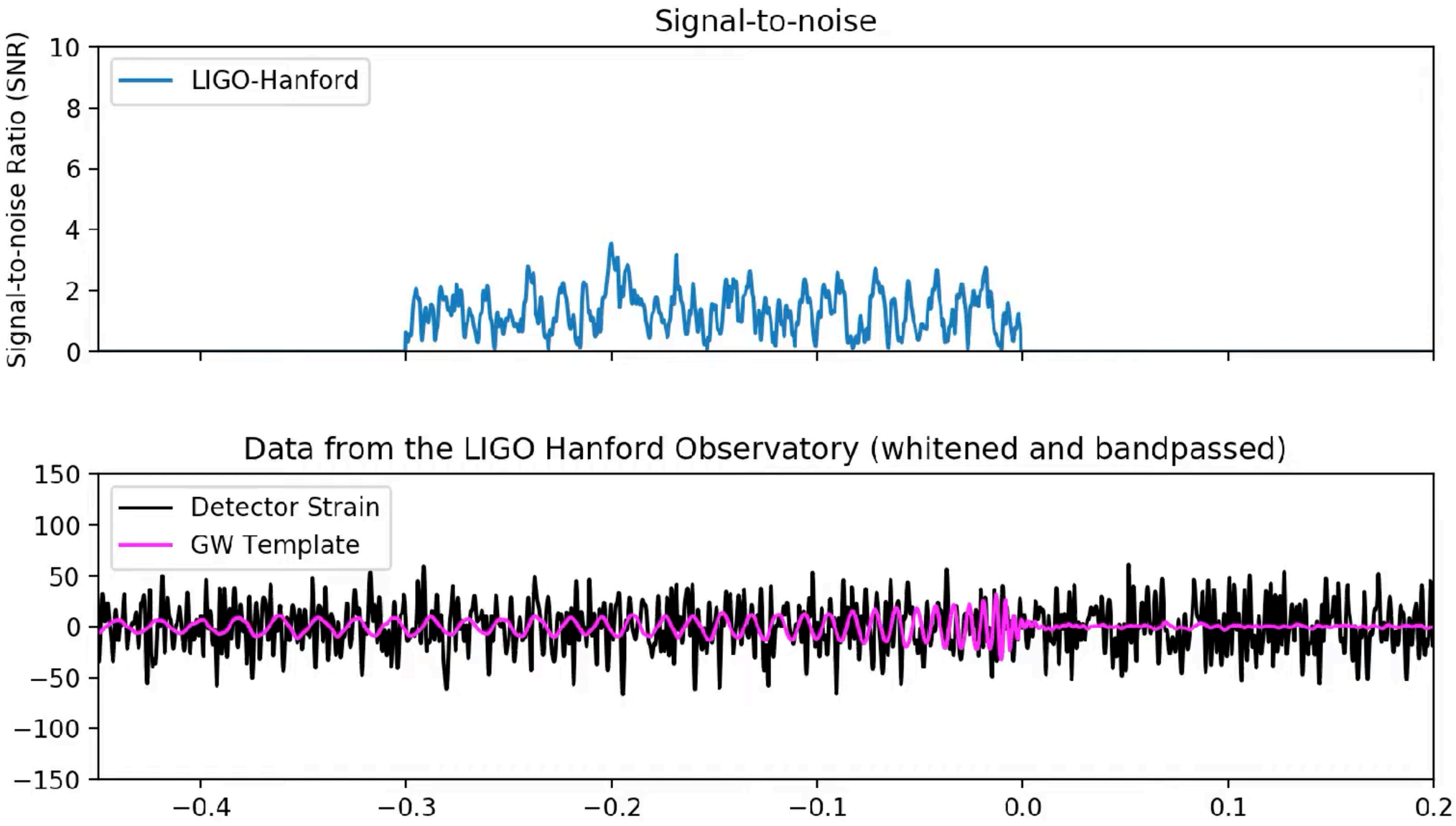


[Credit: T. Pyle, Caltech/MIT/LIGO Lab]

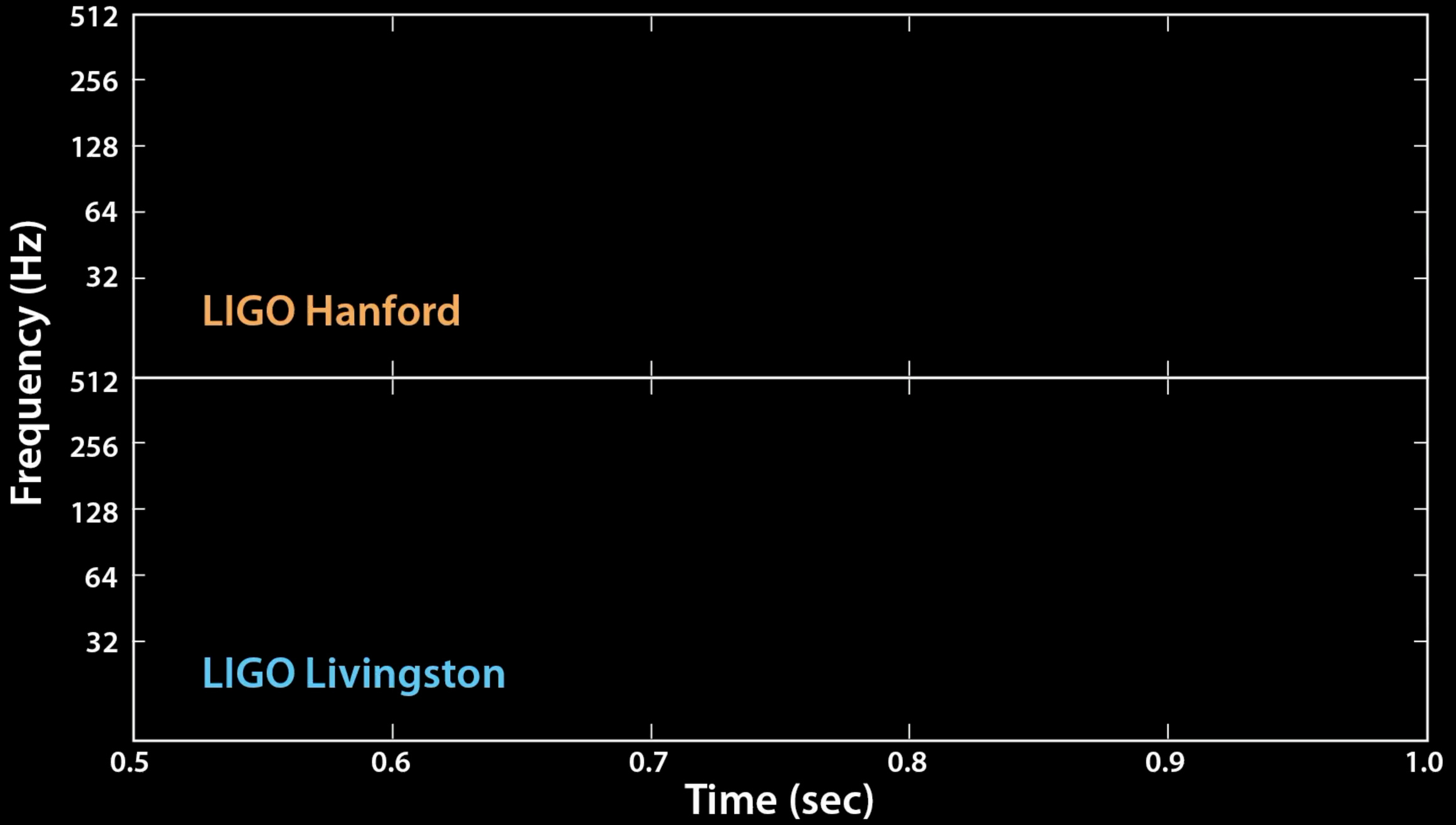

H1
10 ms light travel time
L1
(a)
Test Mass
L_y = 4 km
Test Mass
Power Recycling
Beam Splitter
L_x = 4 km
Laser Source
20 W
Test Mass
100 kW Circulating Power
Test Mass
Signal Recycling
Photodetector
(b)
H1
L1
10^{-21}
10^{-22}
10^{-23}
Strain noise ($Hz^{-1/2}$)
20
100
1000
Frequency (Hz)

[Credit: LIGO]

Matched-filtering

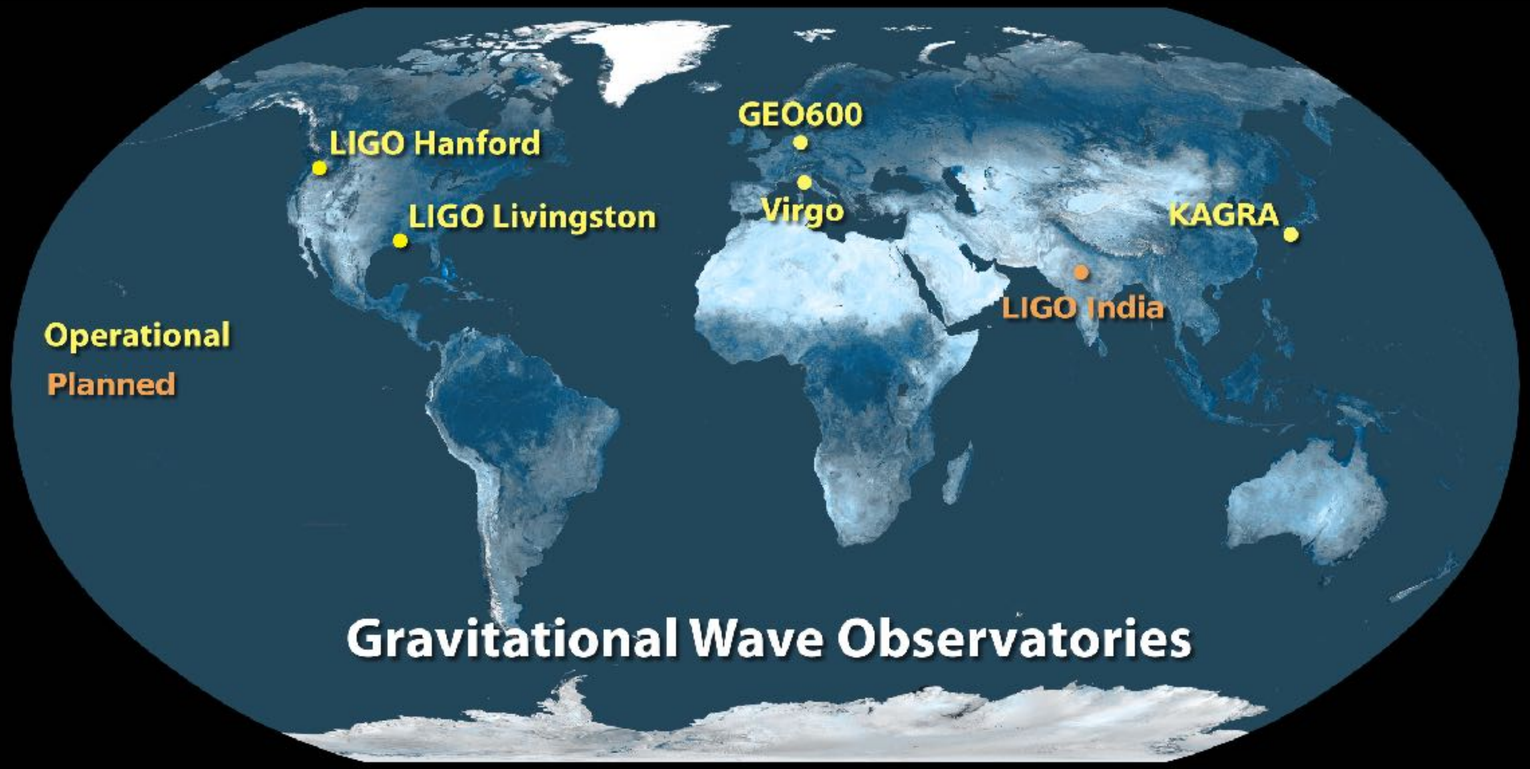


[Credit: Alex Nitz]



[Credit: LIGO/VIRGO]

A *global* gravitational wave detector network



[Hanford, US]

[Livingston, US]

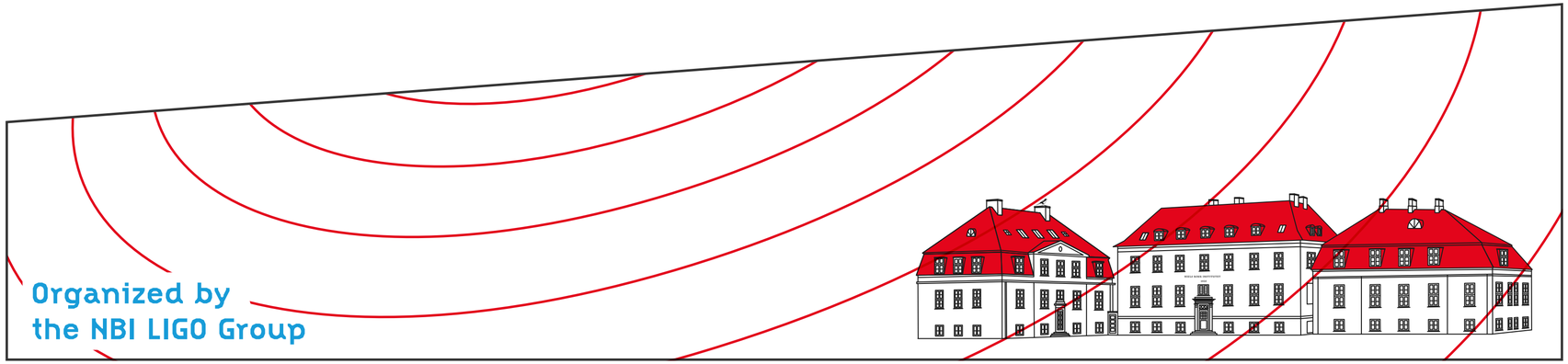
[Virgo, Italy]

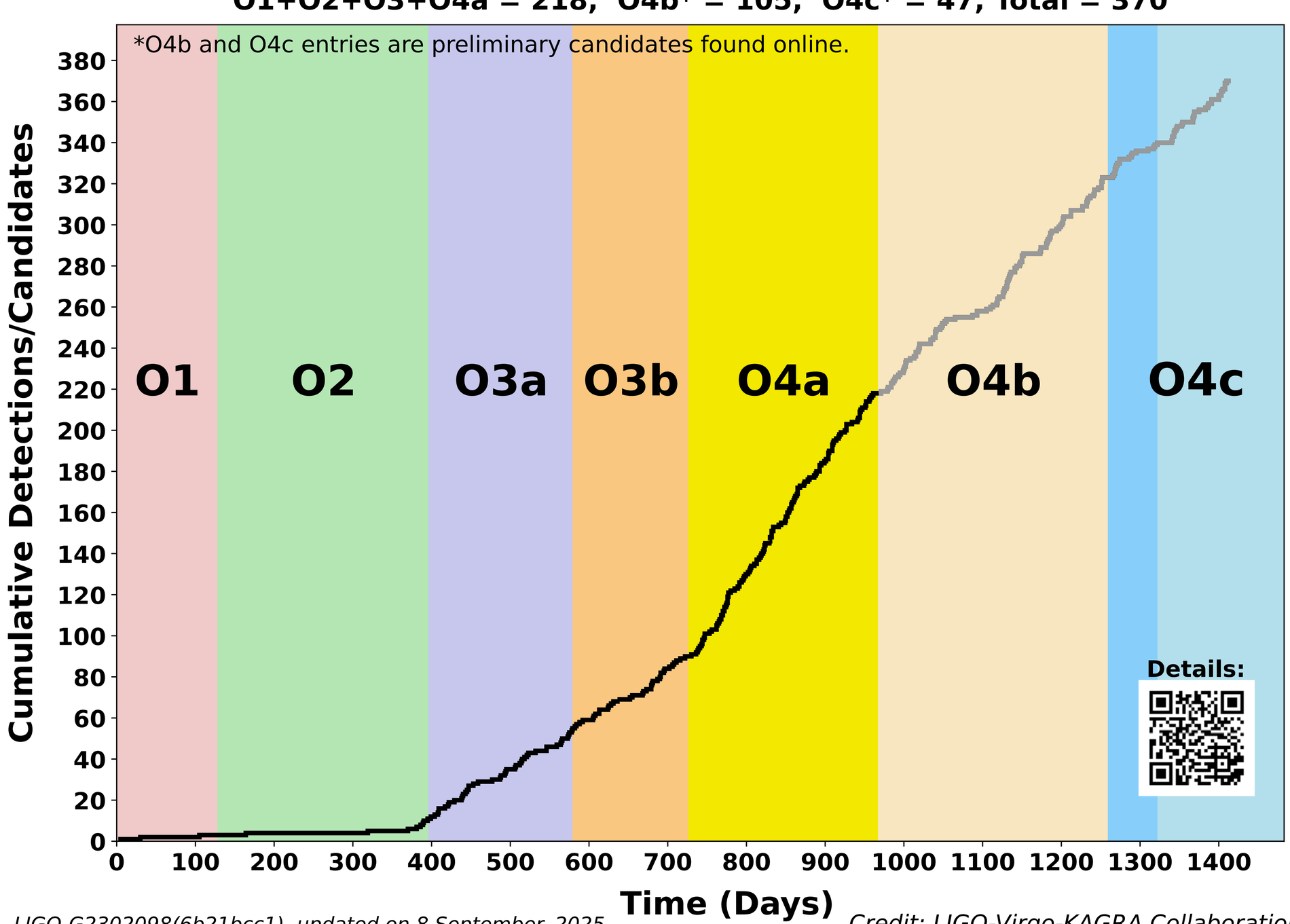
[KAGRA, Japan]

[Lorena @LIGO Livingston, 2015]

[Juno @Virgo, 2018]

[Rico & Jose @KAGRA, 2023]

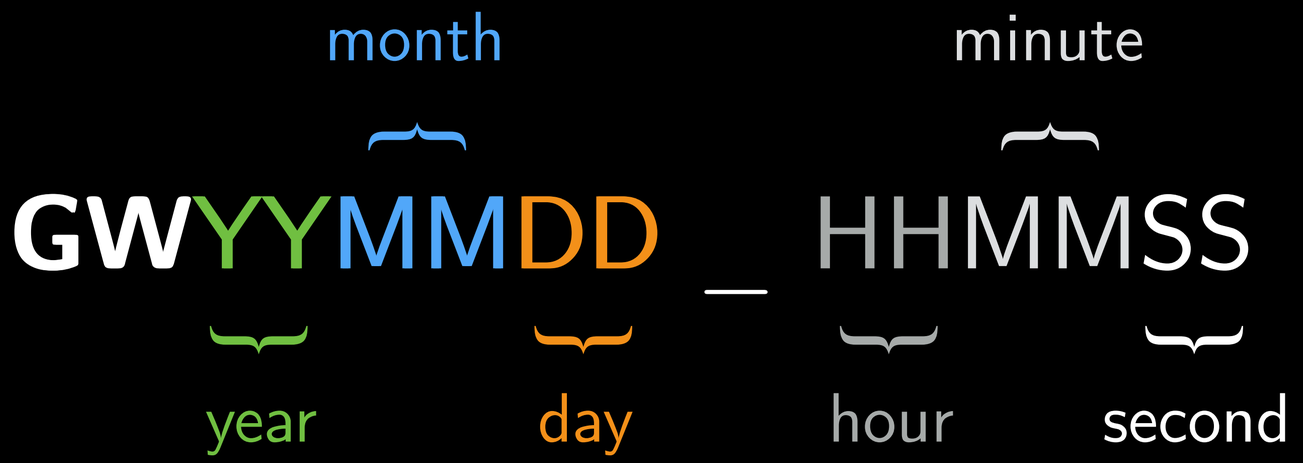

Organized by
the NBI LIGO Group



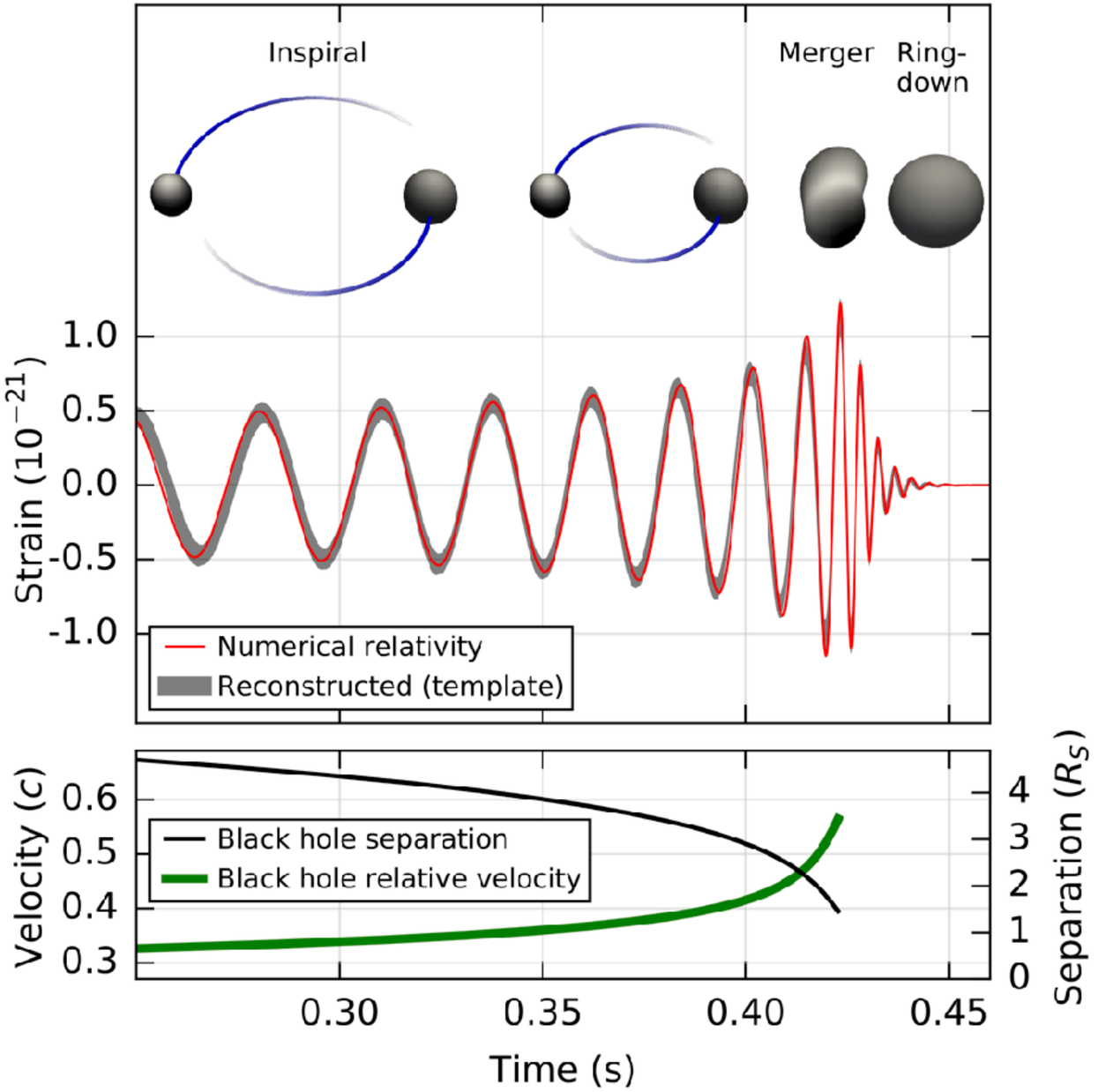
LIGO-G2302098(6b21bcc1), updated on 8 September, 2025

Credit: LIGO-Virgo-KAGRA Collaboration

Gravitational wave phone numbers

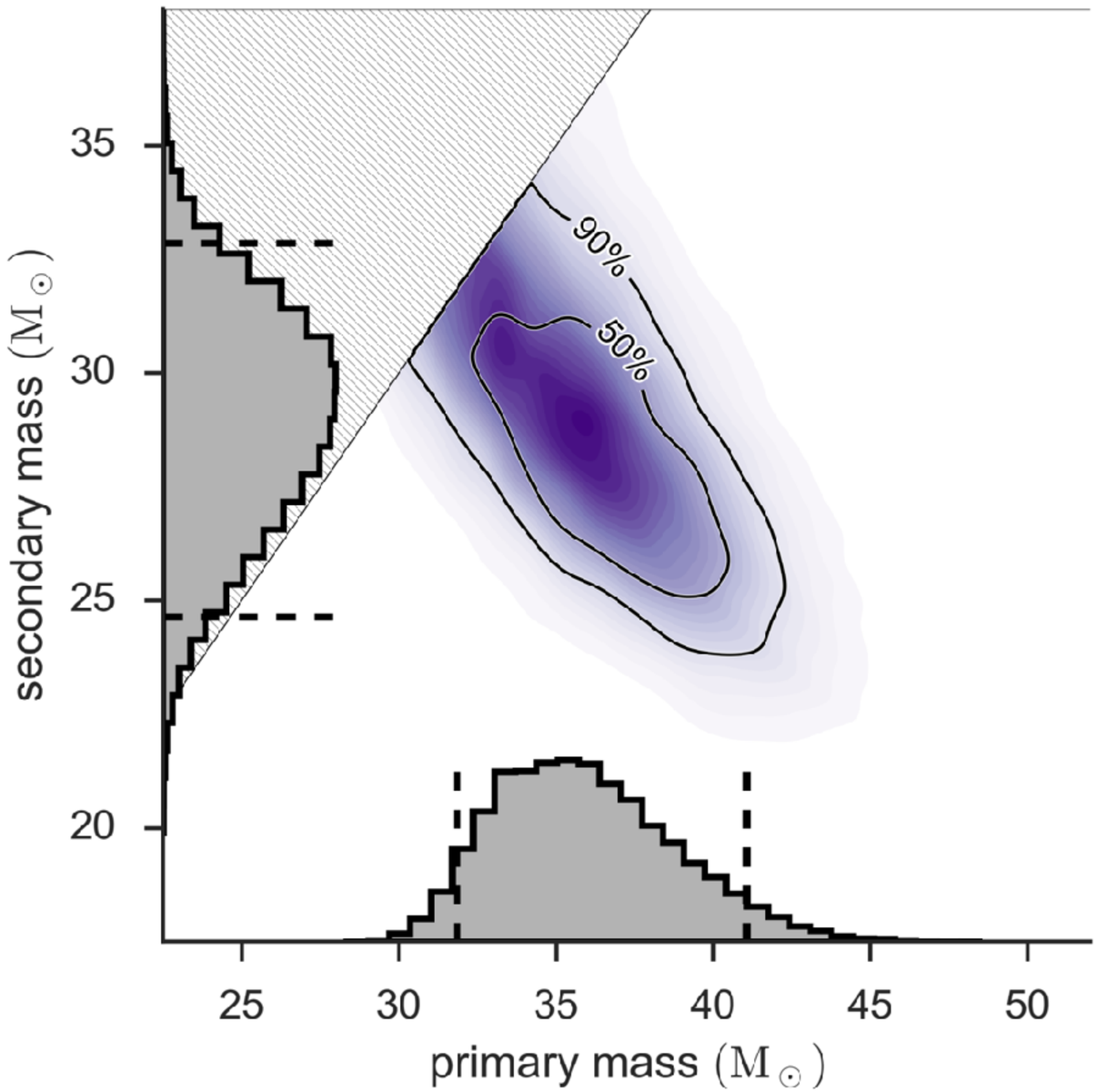


GW150914: the first event!



[GW150914]

GW150914: learning about the signal properties!

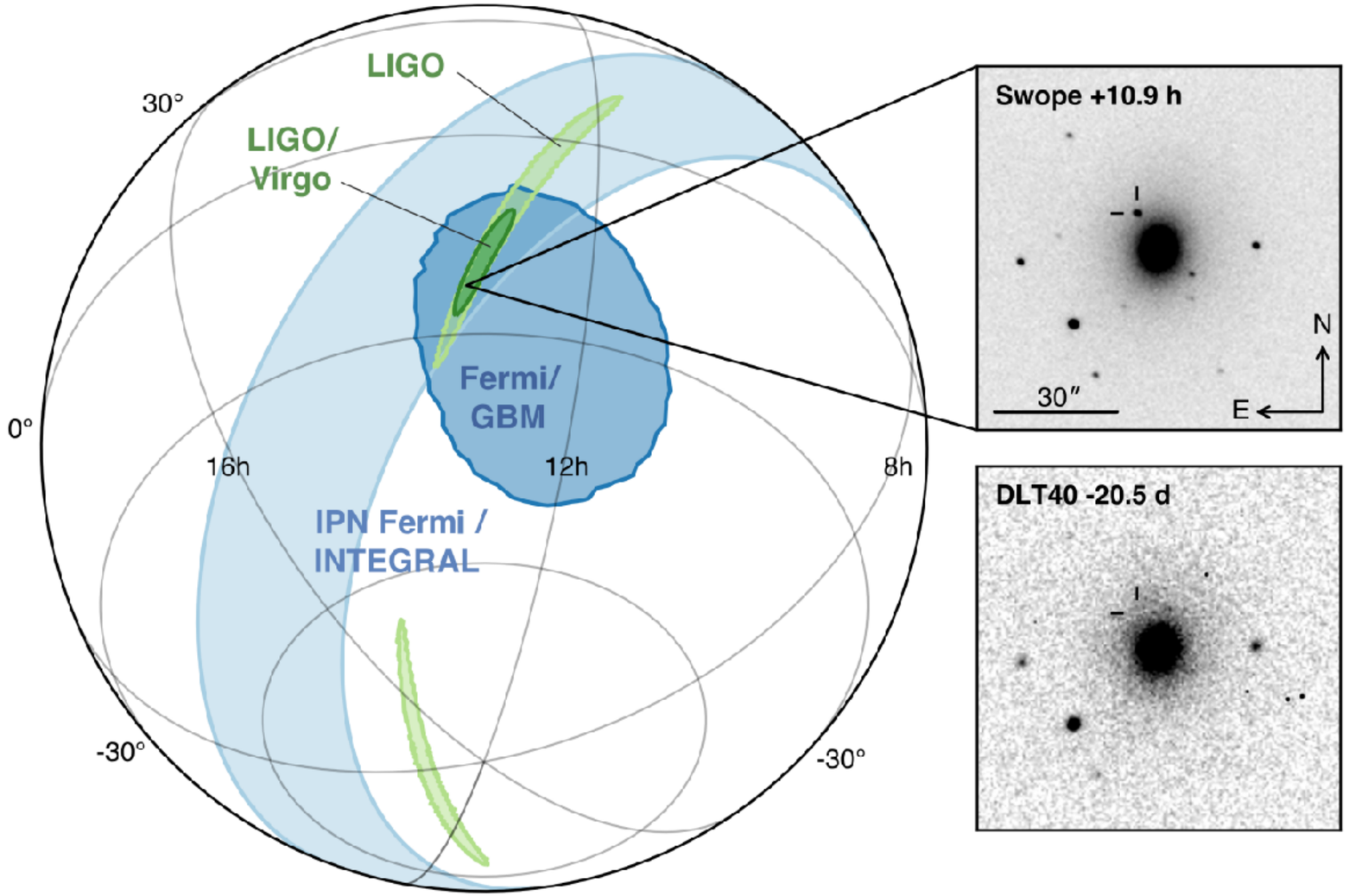


[GW150914]

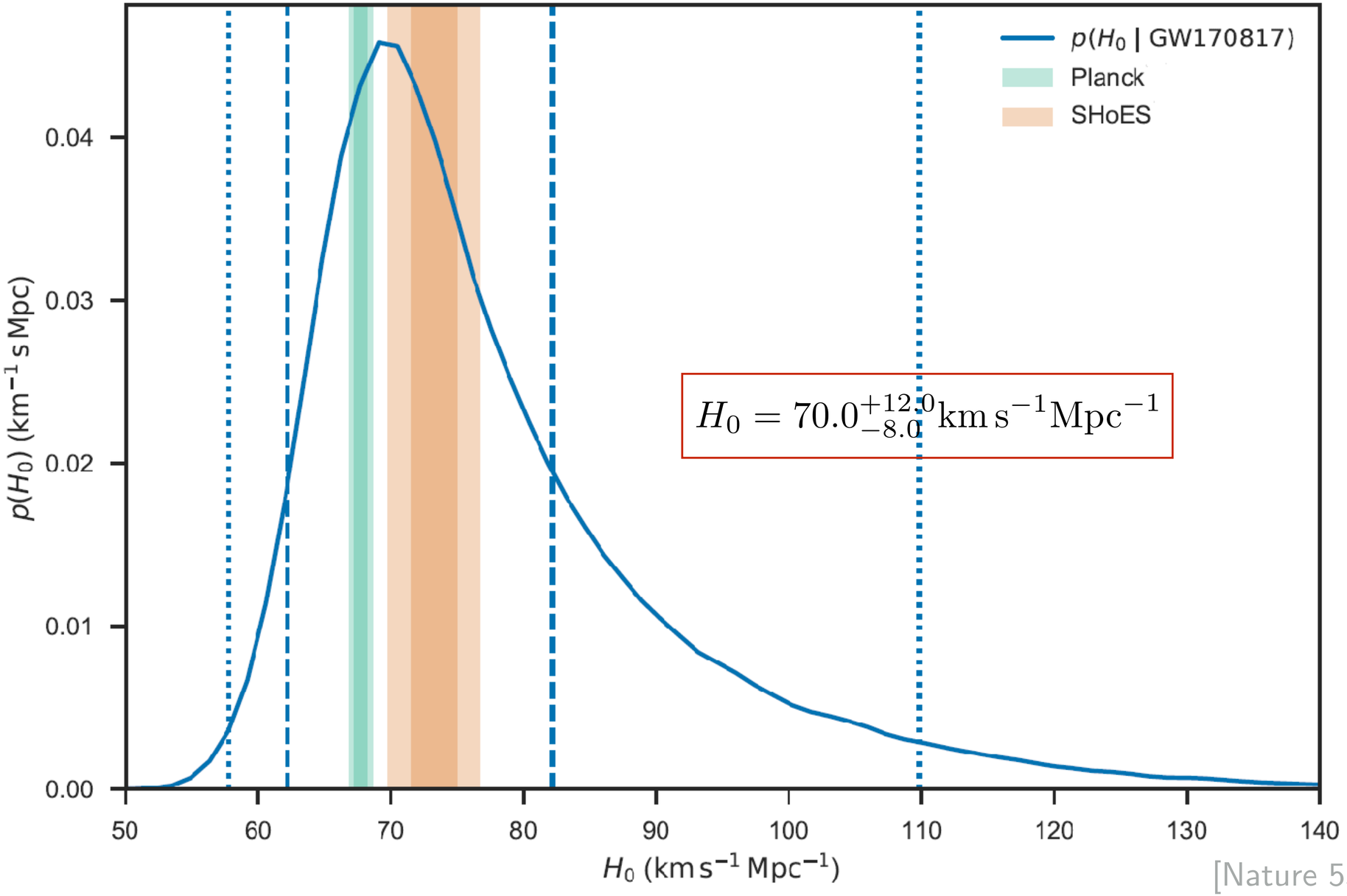
Binary neutron star mergers

[Credit: NASA's Goddard Space Flight Center/CI Lab]

GW170817: first multi-messenger event!

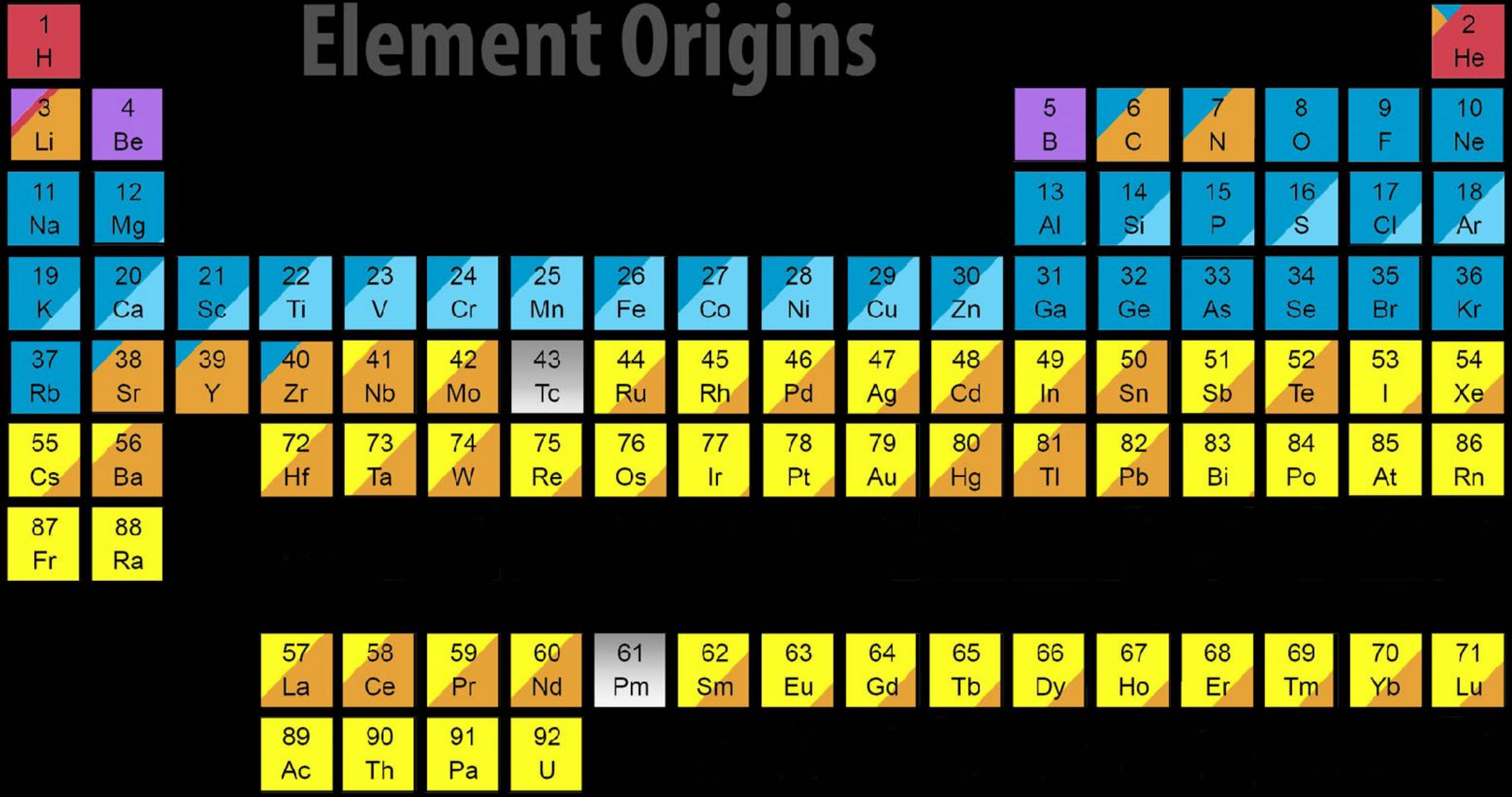


Gravitational waves are standard sirens



[Nature 551, 85 (2017)]

Element Origins

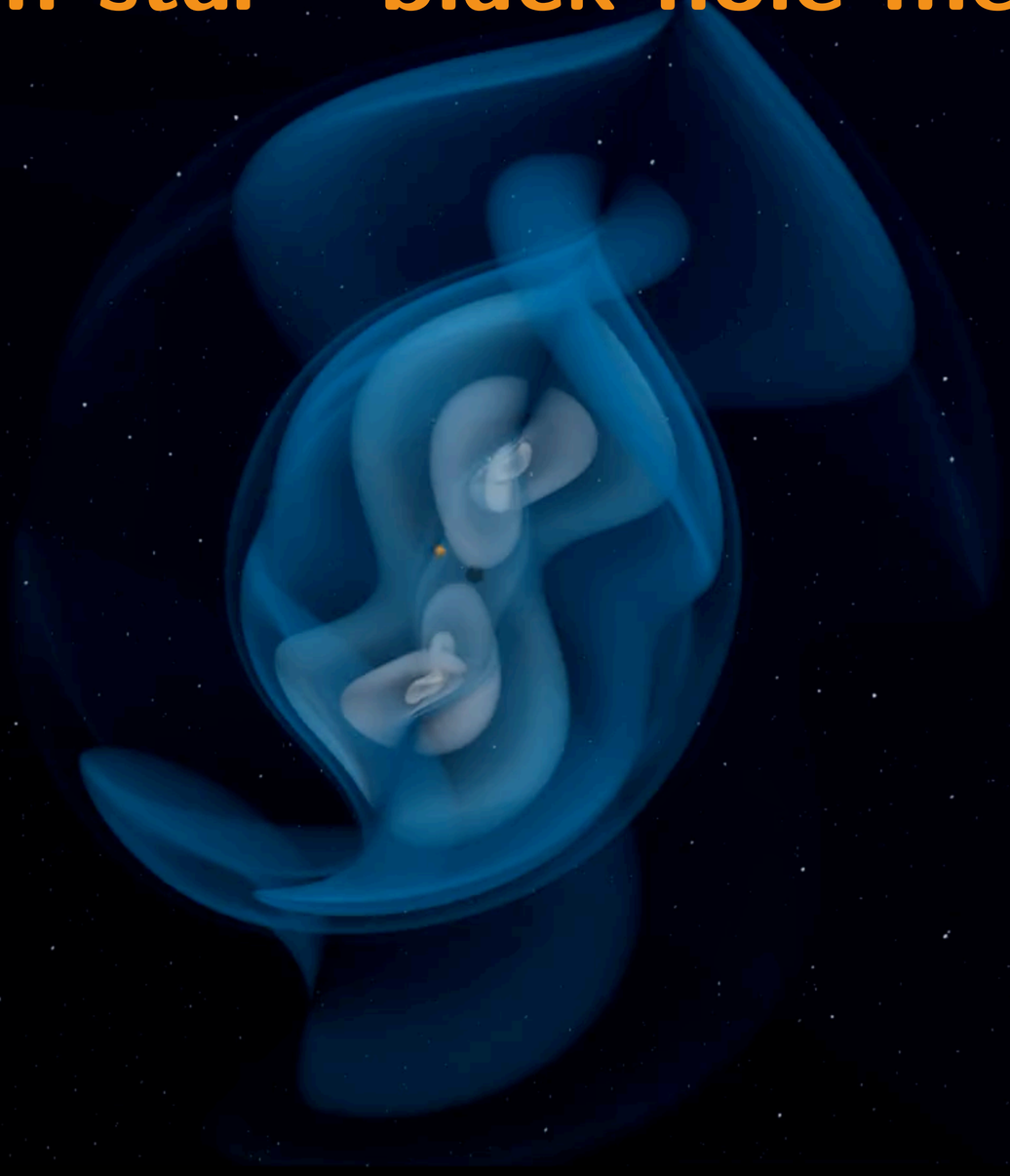


Merging Neutron Stars **Exploding Massive Stars** **Big Bang**

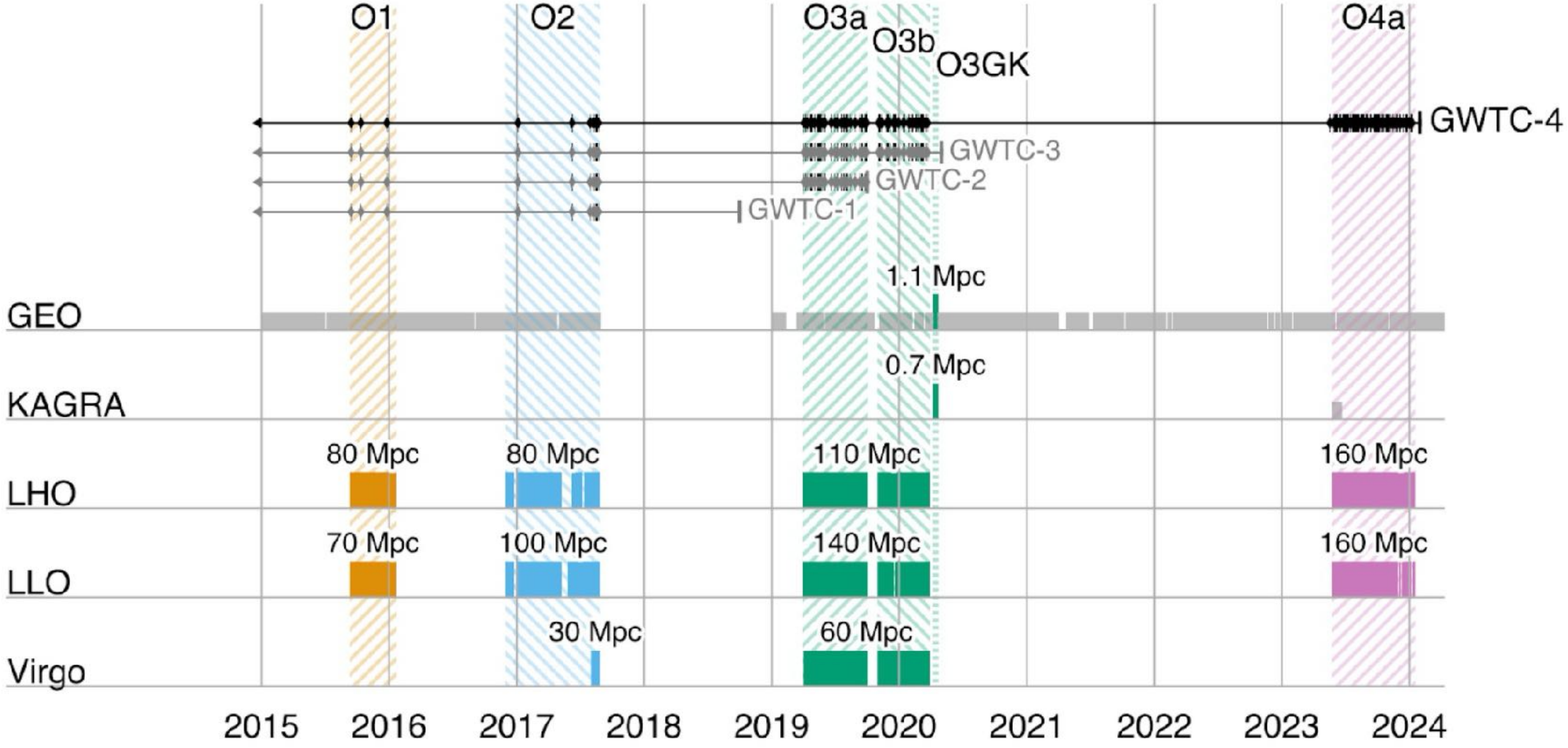
Dying Low Mass Stars **Exploding White Dwarfs** **Cosmic Ray Fission**

Based on graphic created by Jennifer Johnson

Neutron star - black hole mergers



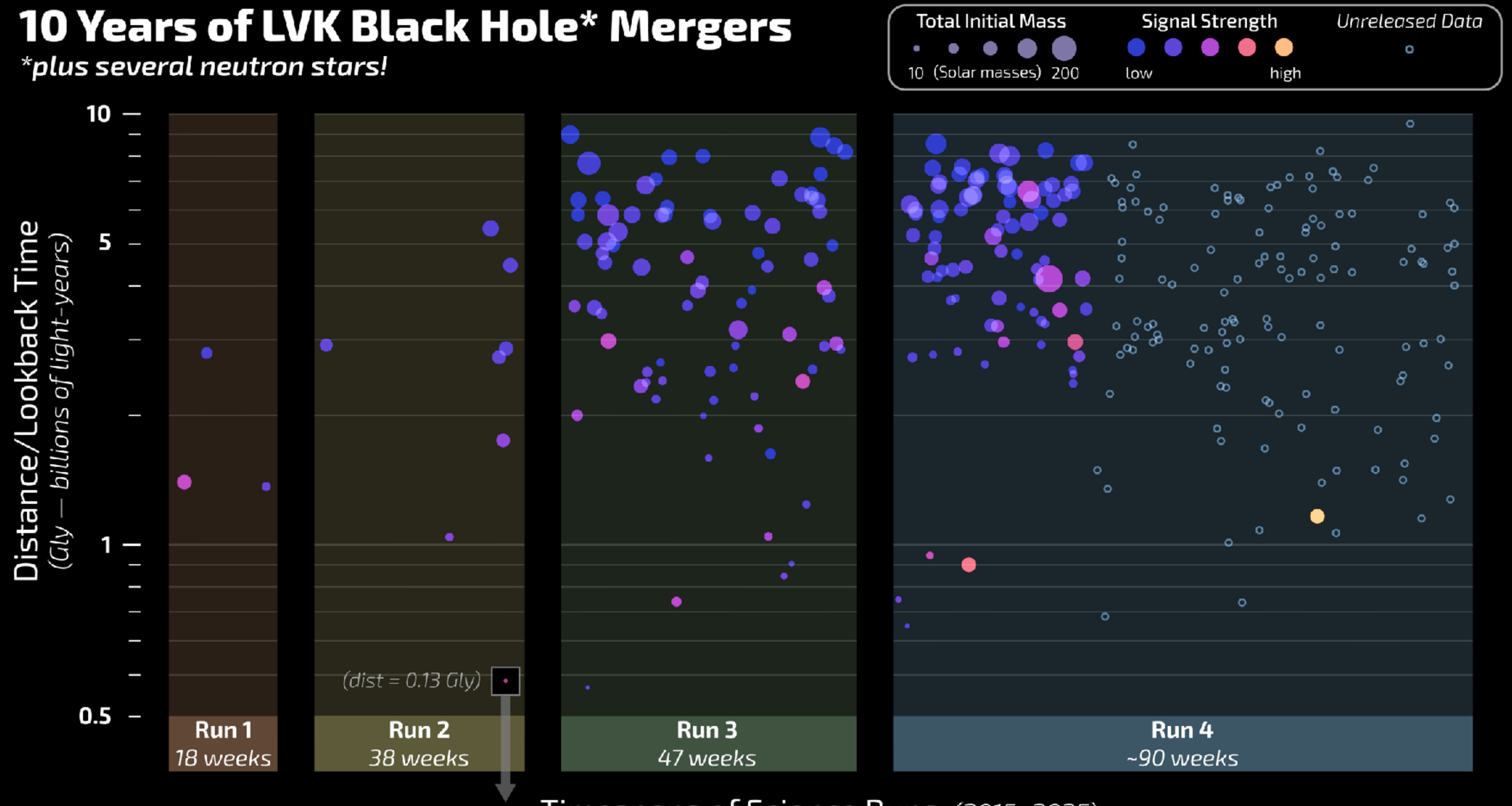
Gravitational Wave Transient Catalogs (GWTC)



[GWTC-4 science summary]

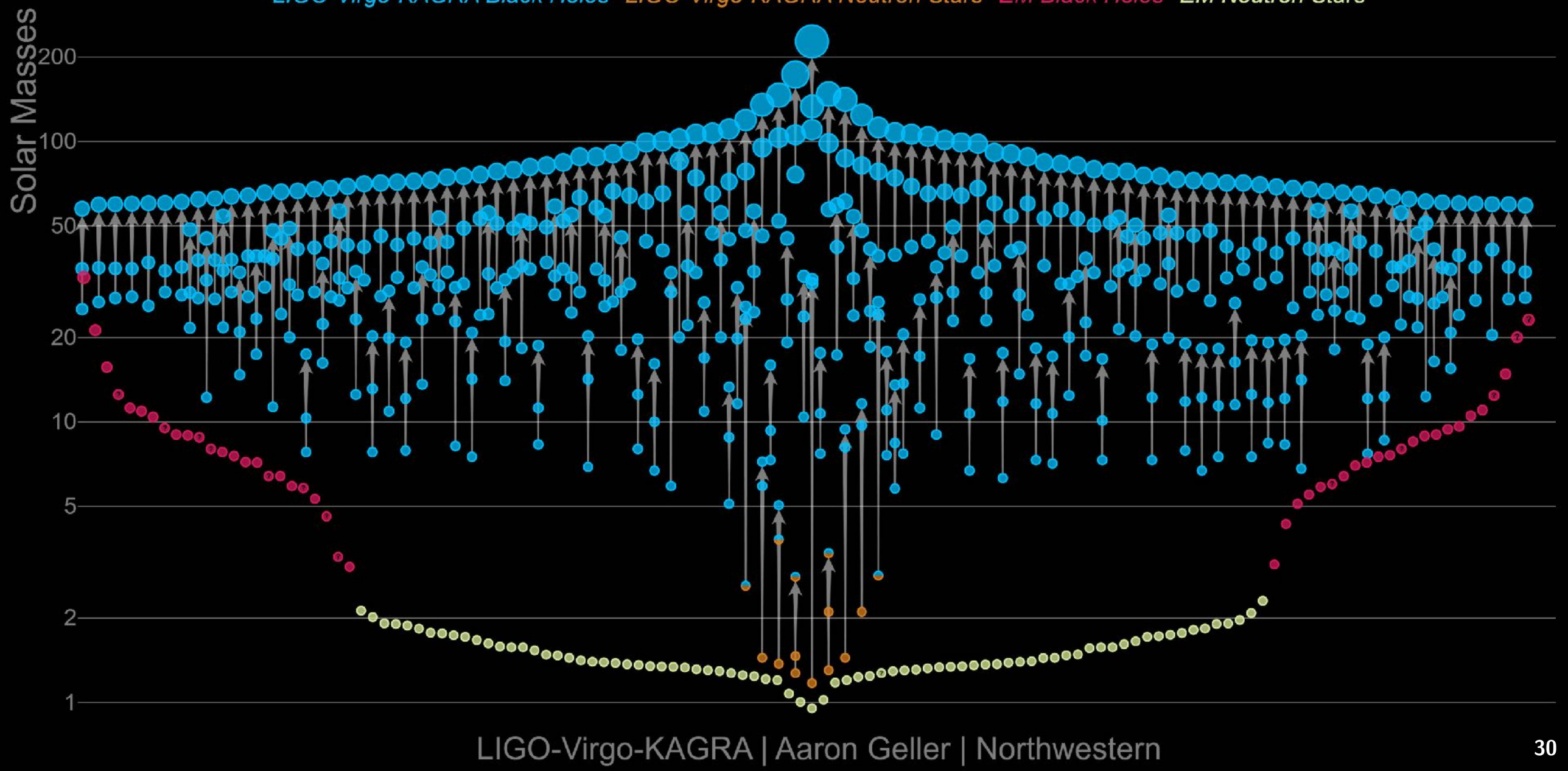
10 Years of LVK Black Hole* Mergers

**plus several neutron stars!*

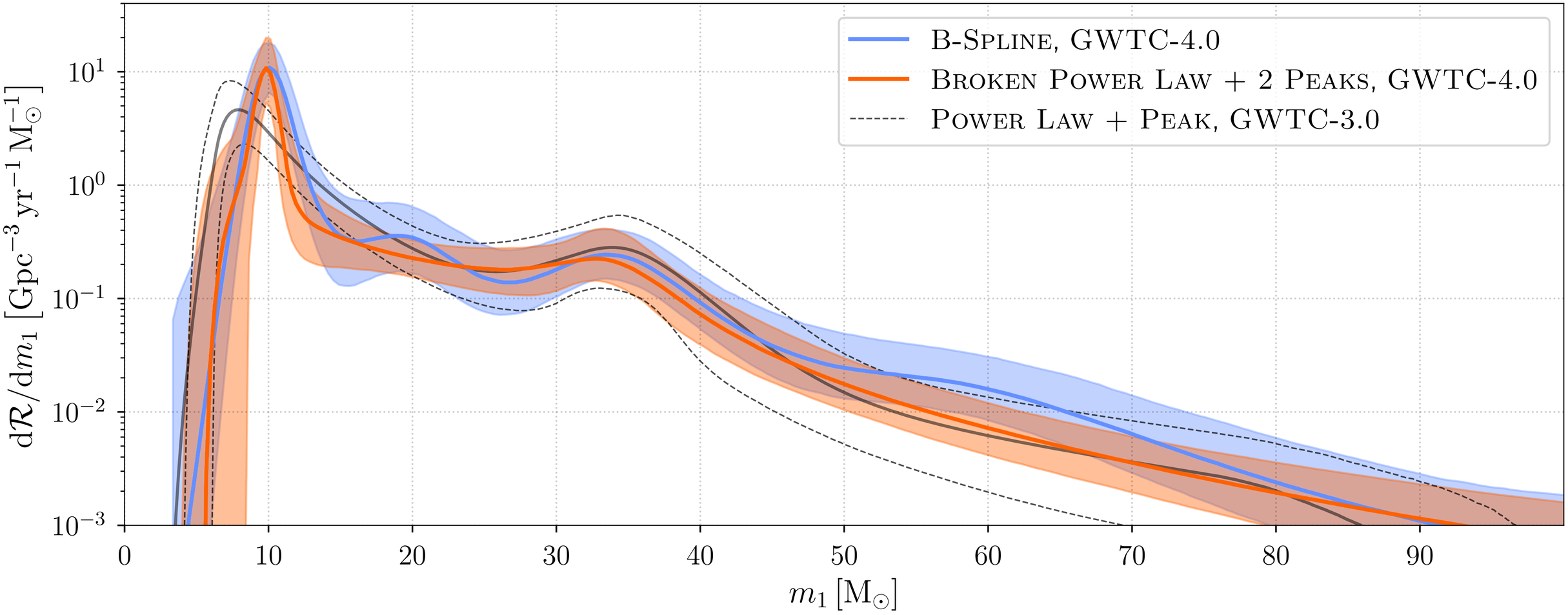


[Credit: LIGO/Caltech/MIT/R. Hurt (IPAC)]

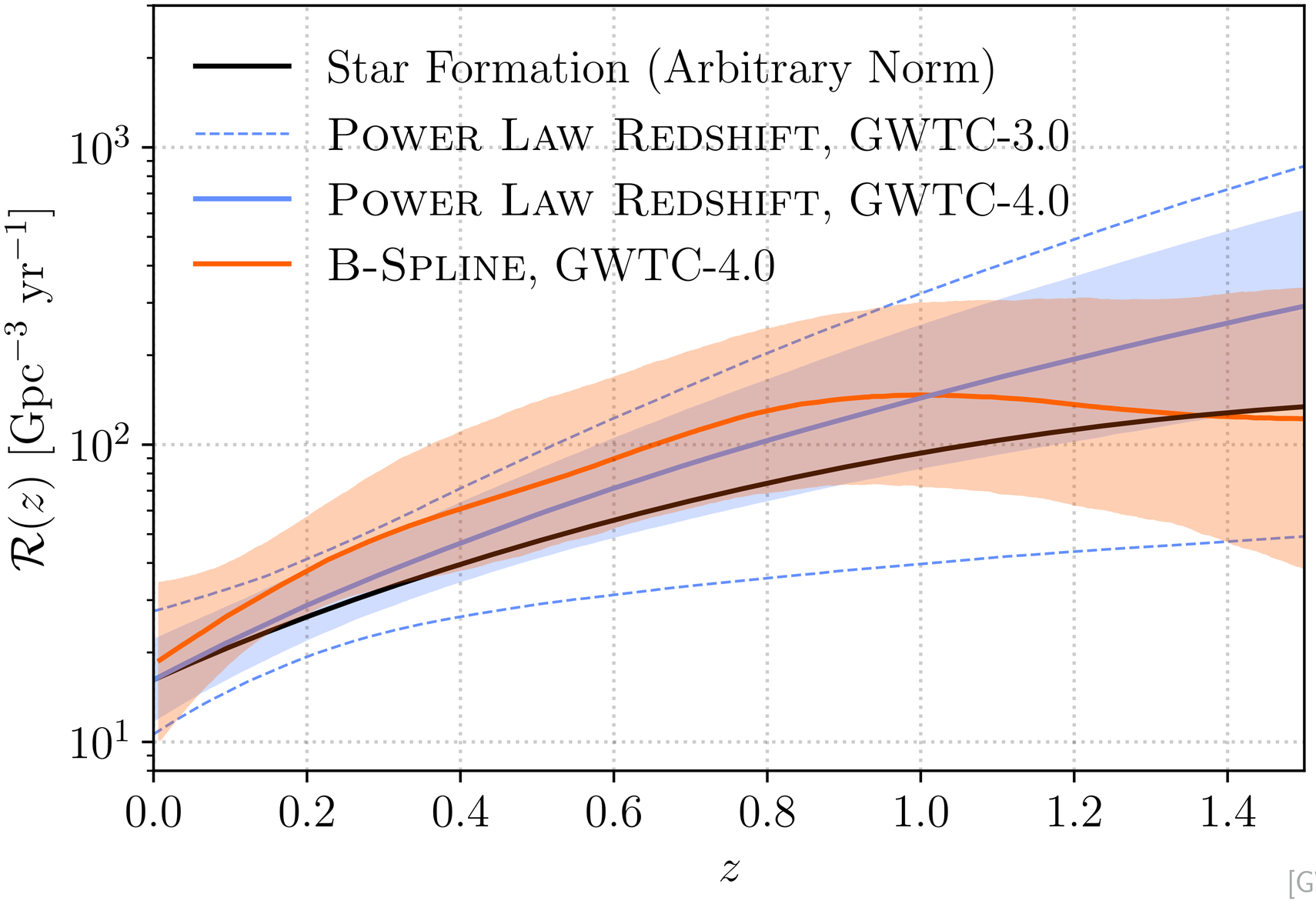
Masses in the Stellar Graveyard



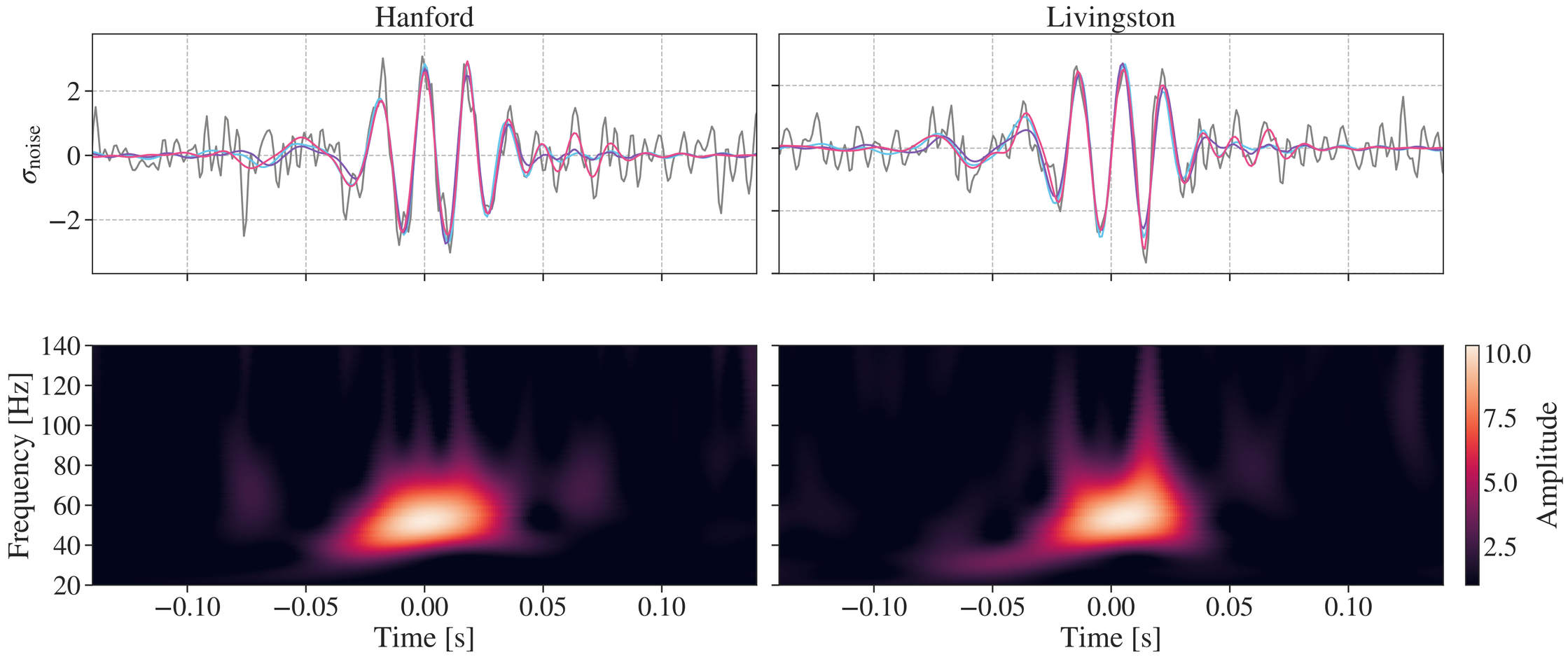
GWTC-4: black holes across the mass spectrum



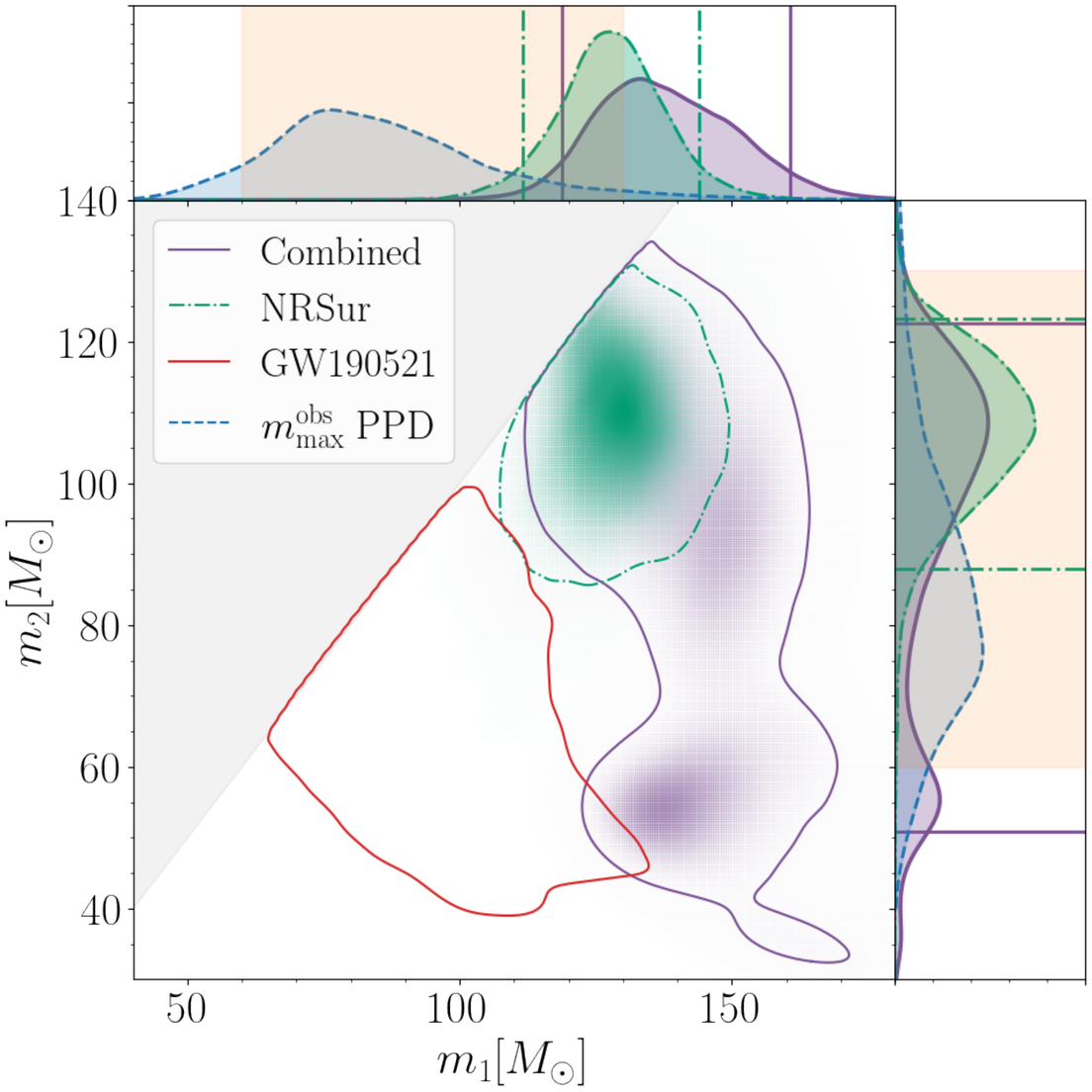
GWTC-4: black holes across cosmic time

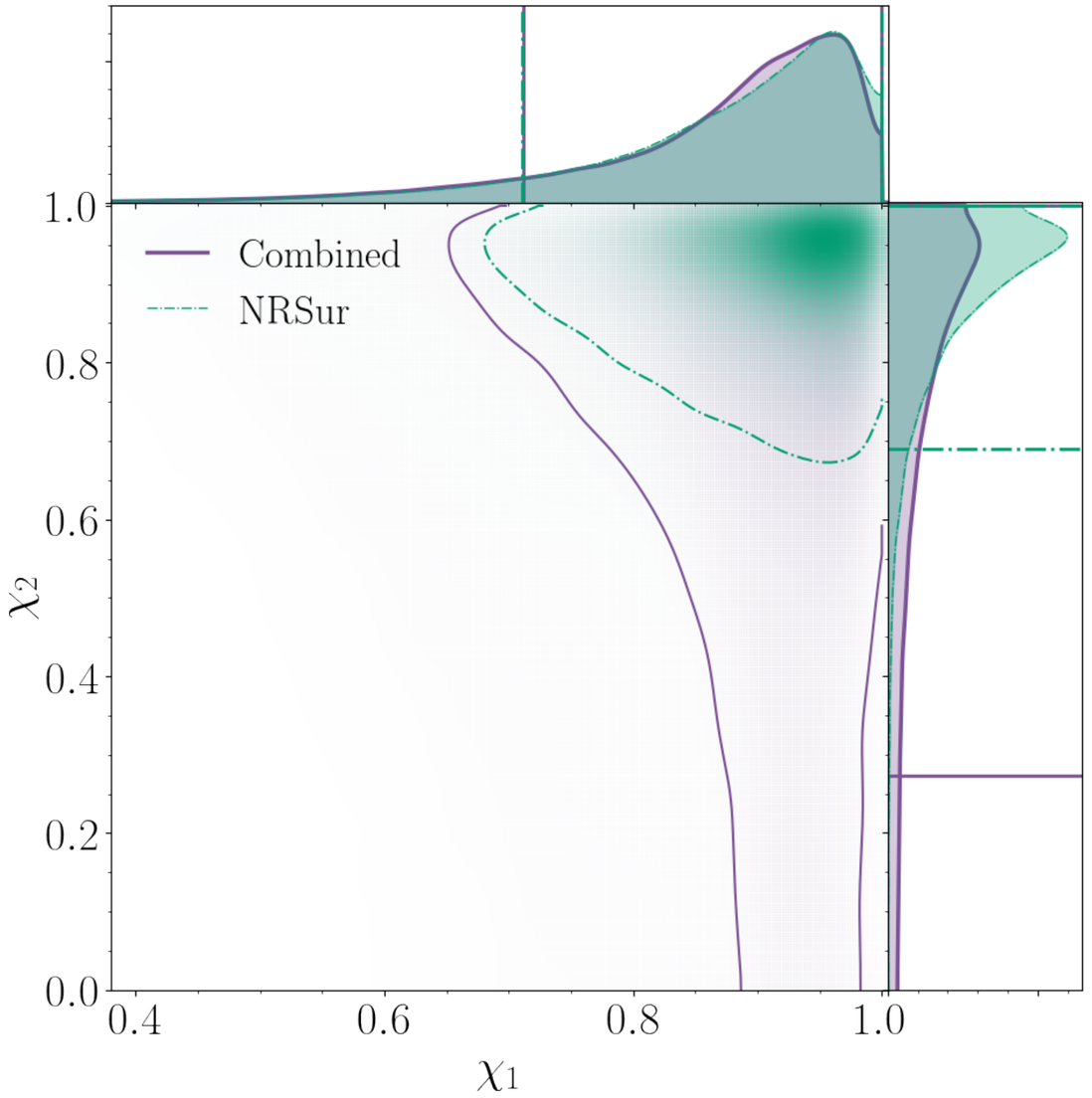


GW231123: the most massive black hole binary (*total mass* between 190 and 265 Msun!)



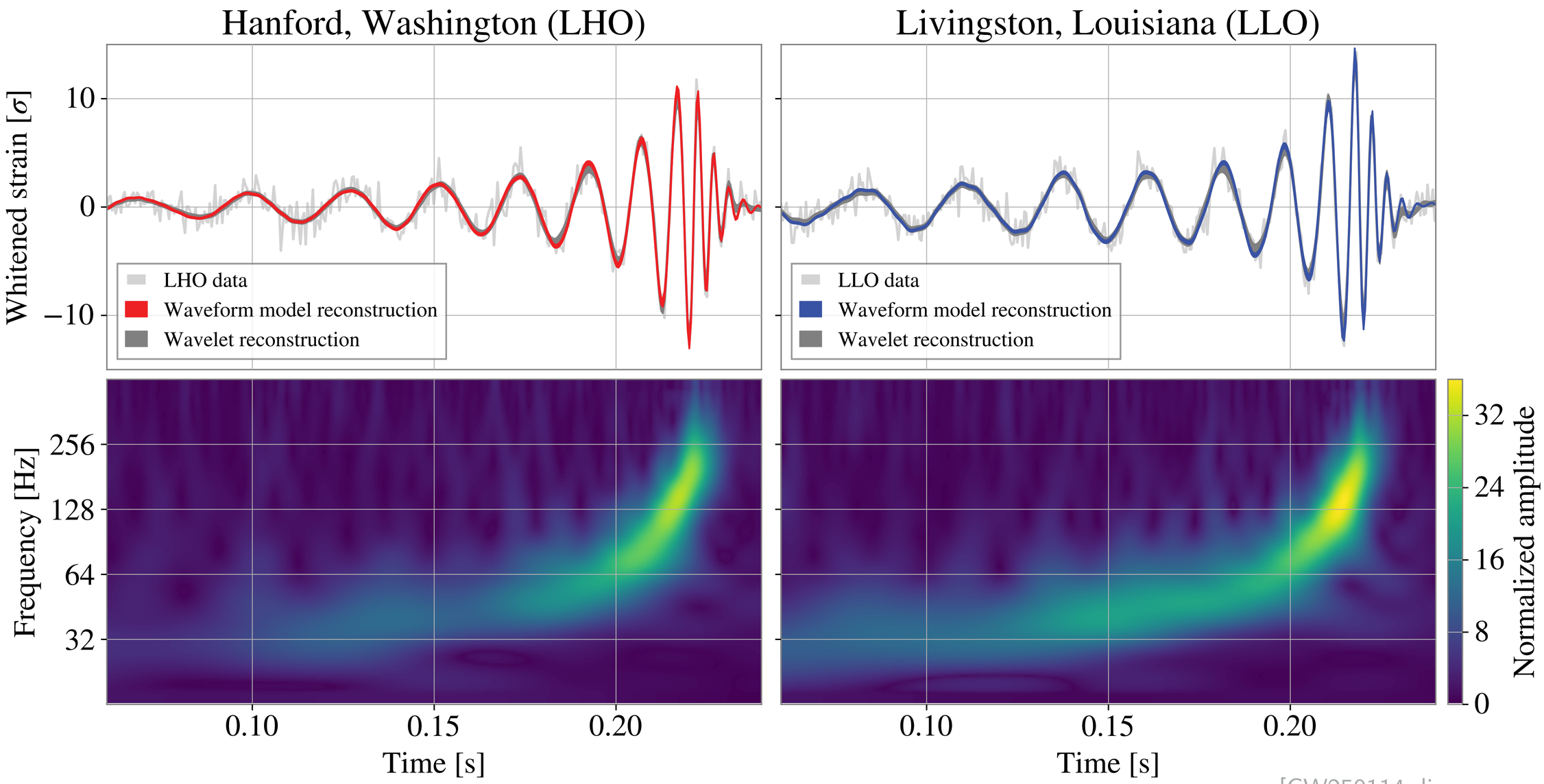
GW231123: puzzling properties (high masses & spins!)





[GW231123 discovery paper]

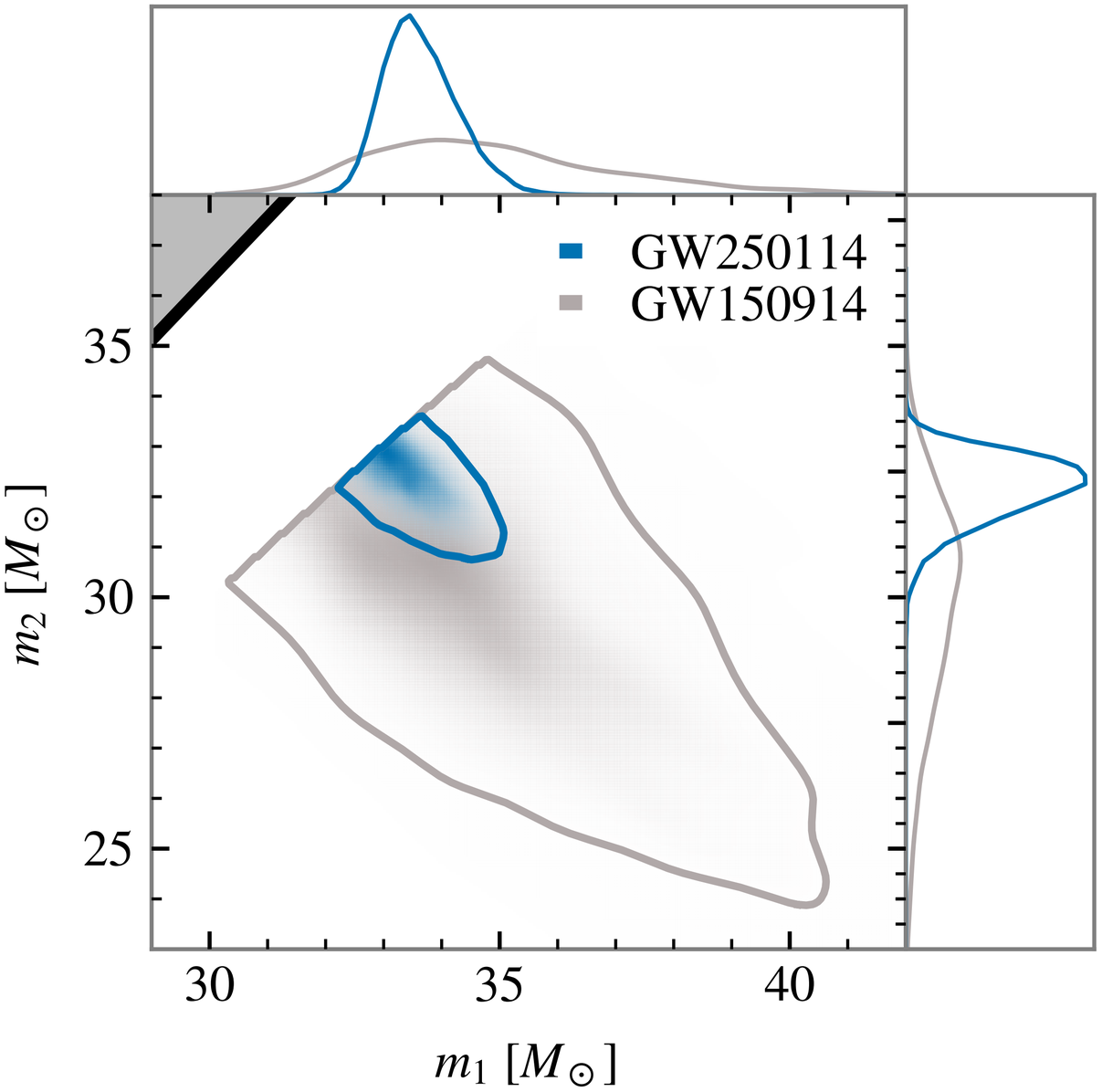
GW250114: the loudest event ever detected (*signal-to-noise* of 80!)



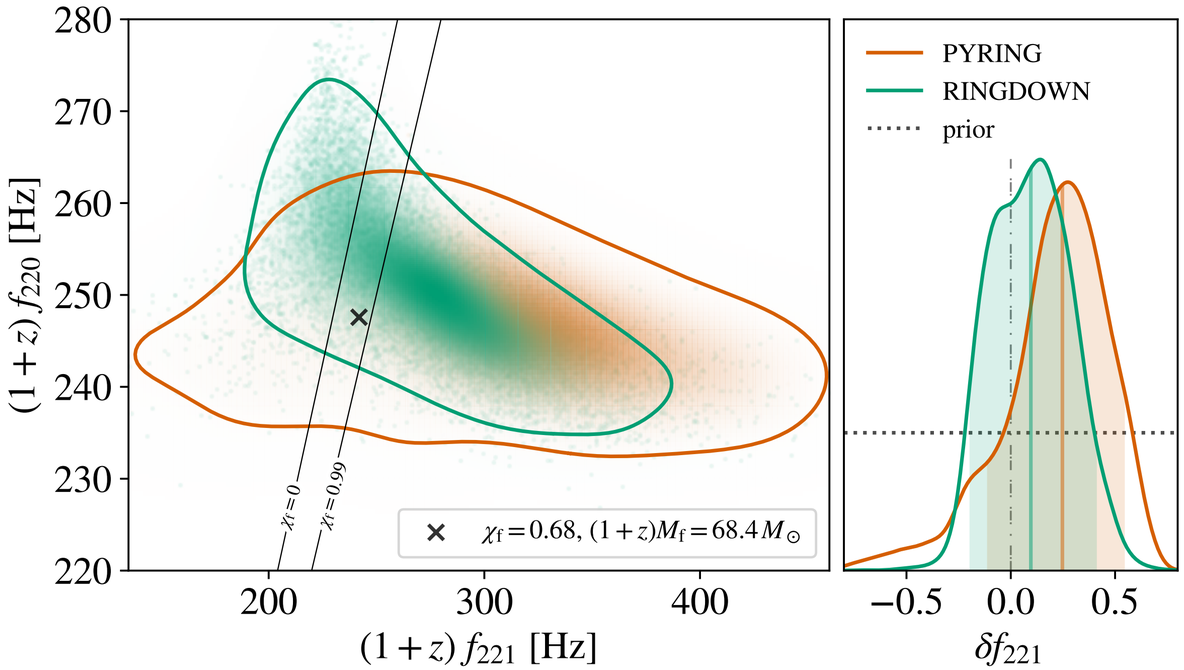
[GW250114 discovery paper]

[Credit: LIGO/Derek Davis (URI)]

GW250114: precision measurements, even in the ring-down!



Hawking area law at 4.4σ!



[GW250114 discovery paper]

O4 LIGO-Virgo-KAGRA papers: there are many!

GWTC-4:

- Introduction to the catalog (arXiv), catalog (arXiv)
- Methods (arXiv)
- Open data (arXiv)
- Population Properties of Merging Compact Binaries (arXiv)
- Constraints on the cosmic expansion (arXiv)
- Test of General Relativity I, II, III (*to appear*)
- Searches for Gravitational Wave Lensing Signatures (*to appear*)

Exceptional events:

- GW231123: most massive (arXiv, *Danish science summary*)
- GW230814: single detector, SNR 40, tests of gravity (arXiv)
- GW250114: loudest ever, SNR 80! (PRL, *Danish science summary*), black hole spectroscopy & tests of gravity (arXiv)

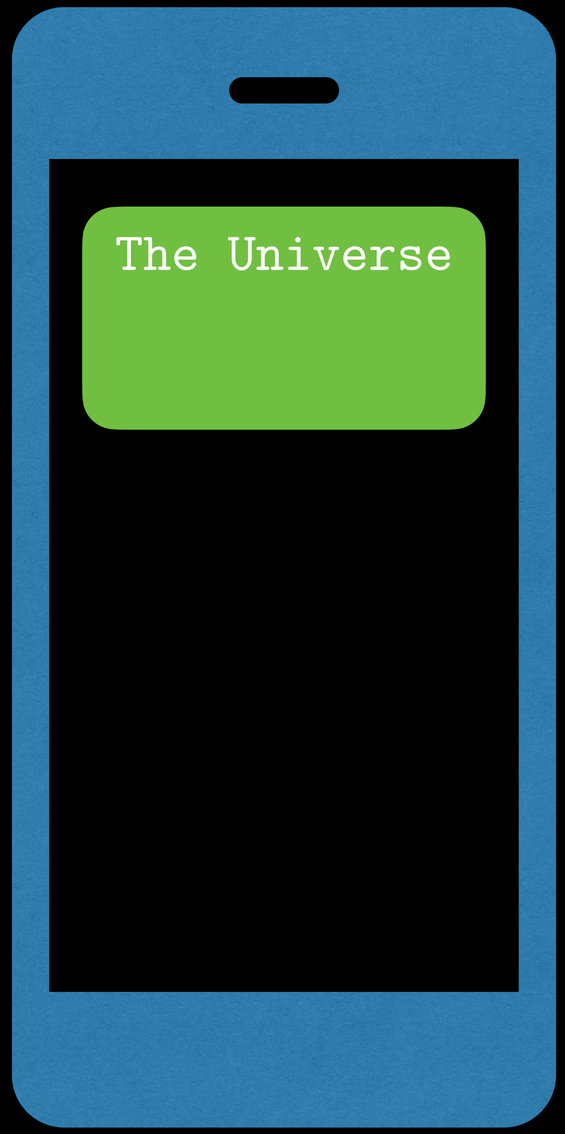
And more: upper limits on stochastic backgrounds (arXiv), searches for continuous sources...

And if you want more, we are still taking data!

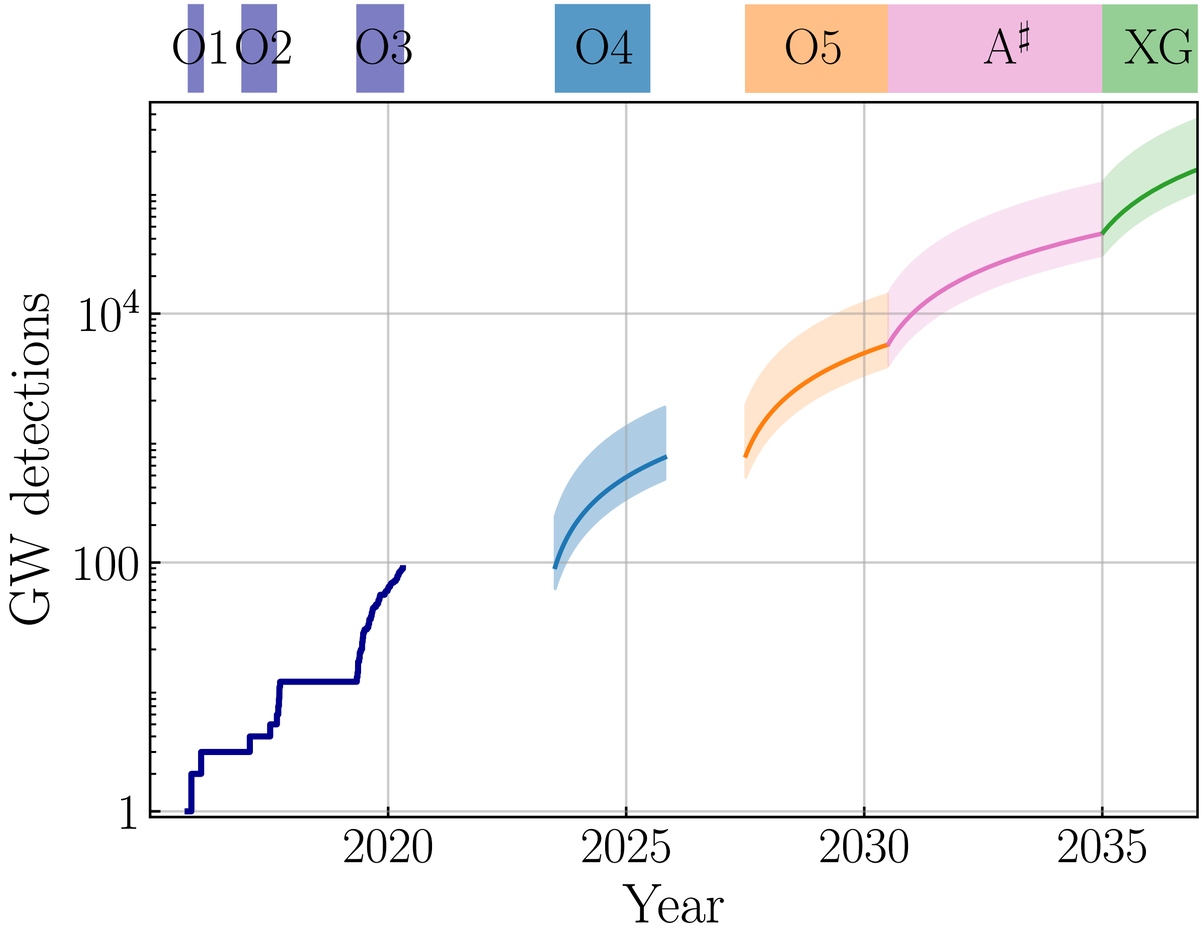
https://gracedb.ligo.org/superevents/public/O4/#

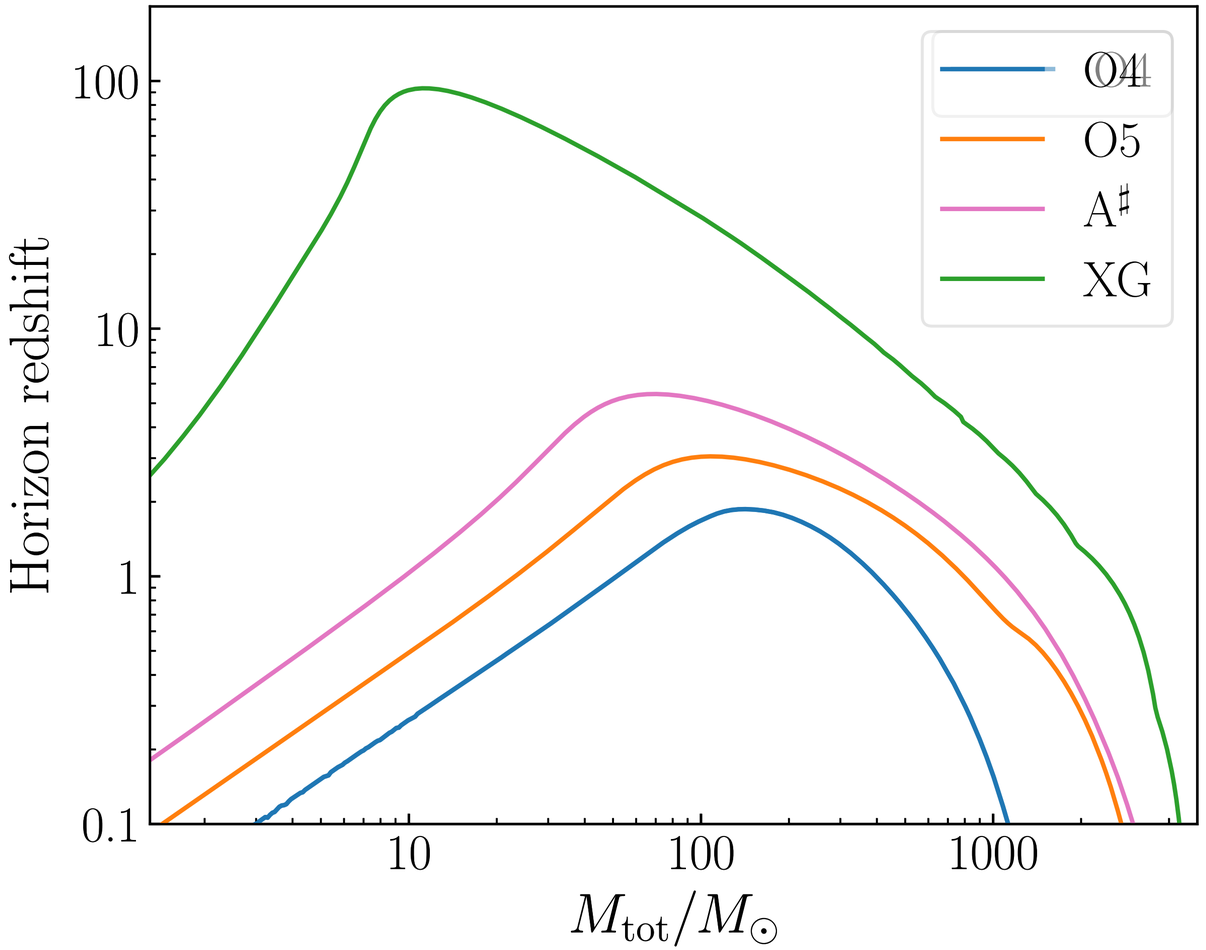
[get alerts for new candidates]

Check arXiv for more papers soon!

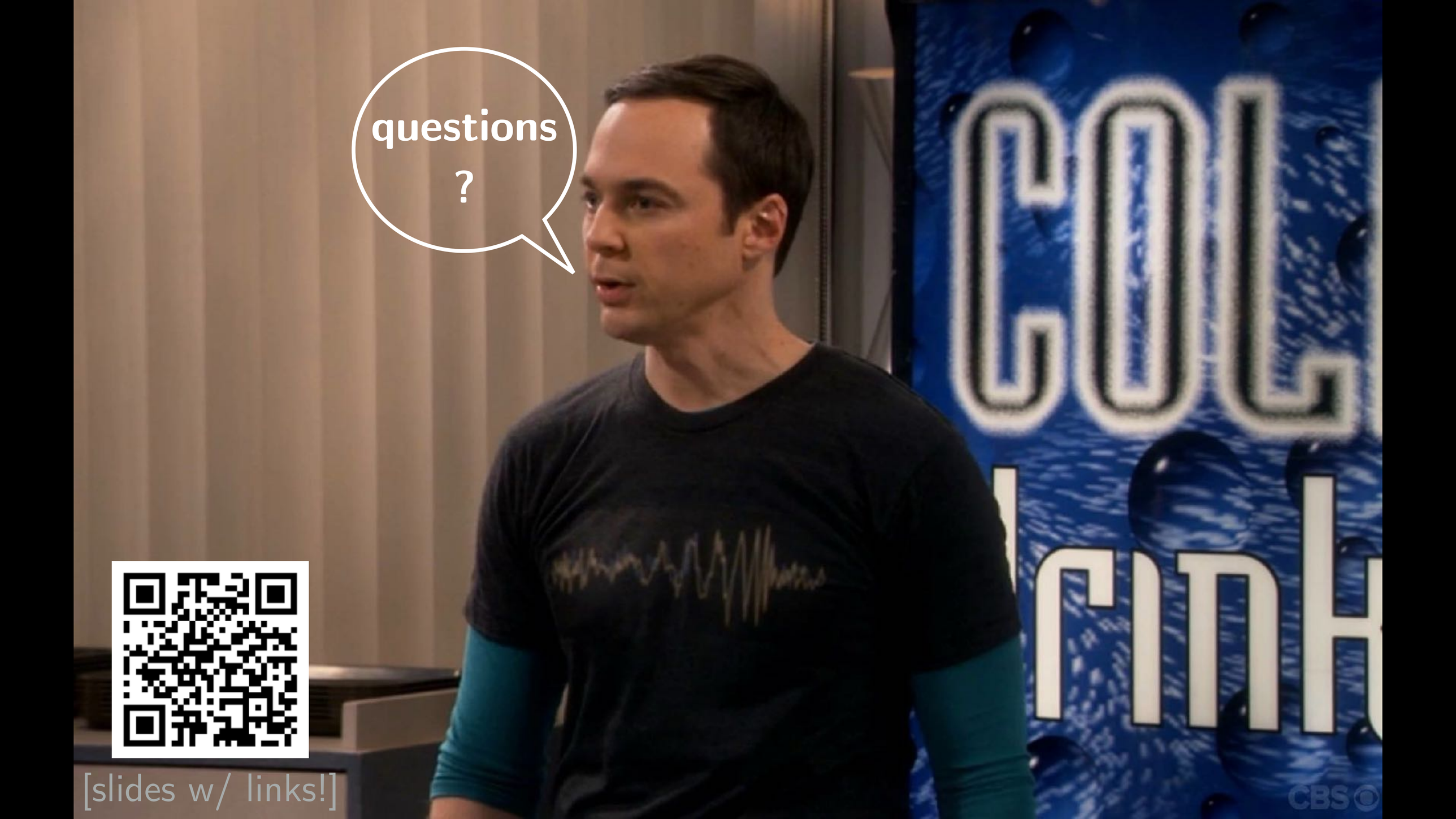


The future: big data & distant Universe!





[XG = Next-Generation ground-based detectors]


questions
?
[slides w/ links!]
CBS

Join us!

NBI LIGO group

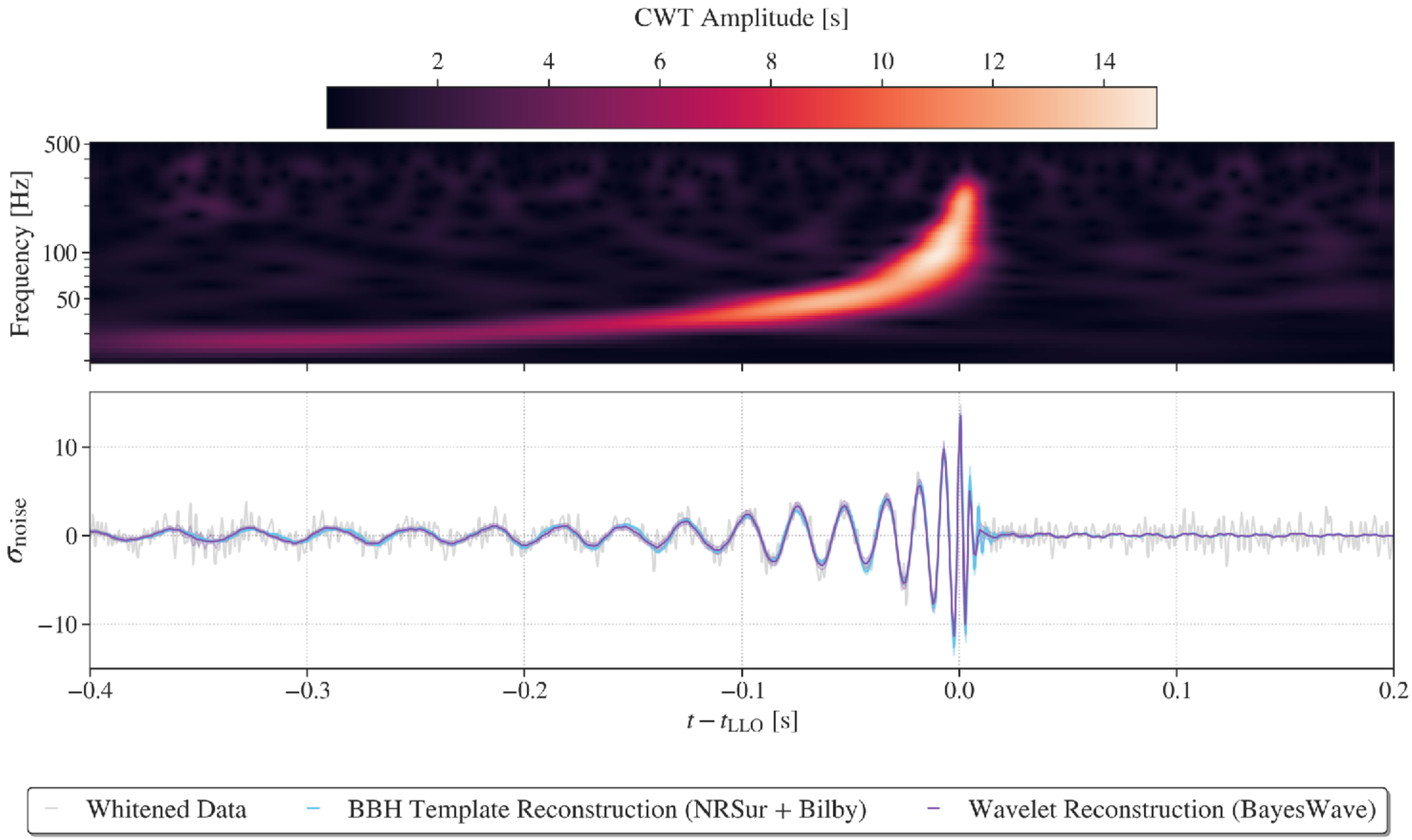
MSc PUK course: “Black holes & Gravitational Waves”

Student resources @ The Center of Gravity

[slides w/ links!]

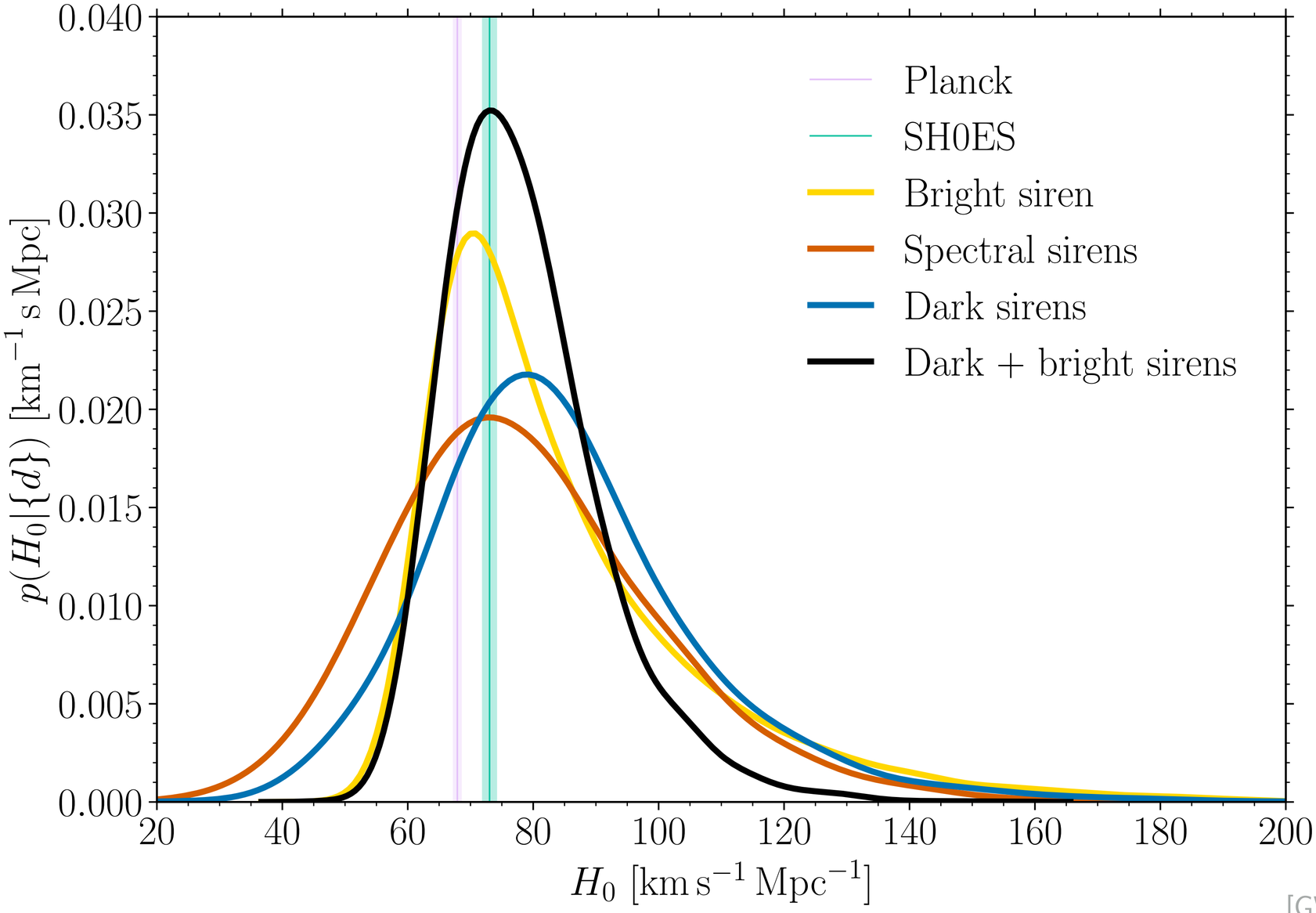
jose.ezquiaga@nbi.ku.dk

GW230814: a loud, single detector event



[GW230814 discovery paper]

GWTC-4: H_0 inference with different methods



[GWTC-4 cosmology paper]