

September 15, 4pm
Margrethe Bohr Salen
Niels Bohr Building

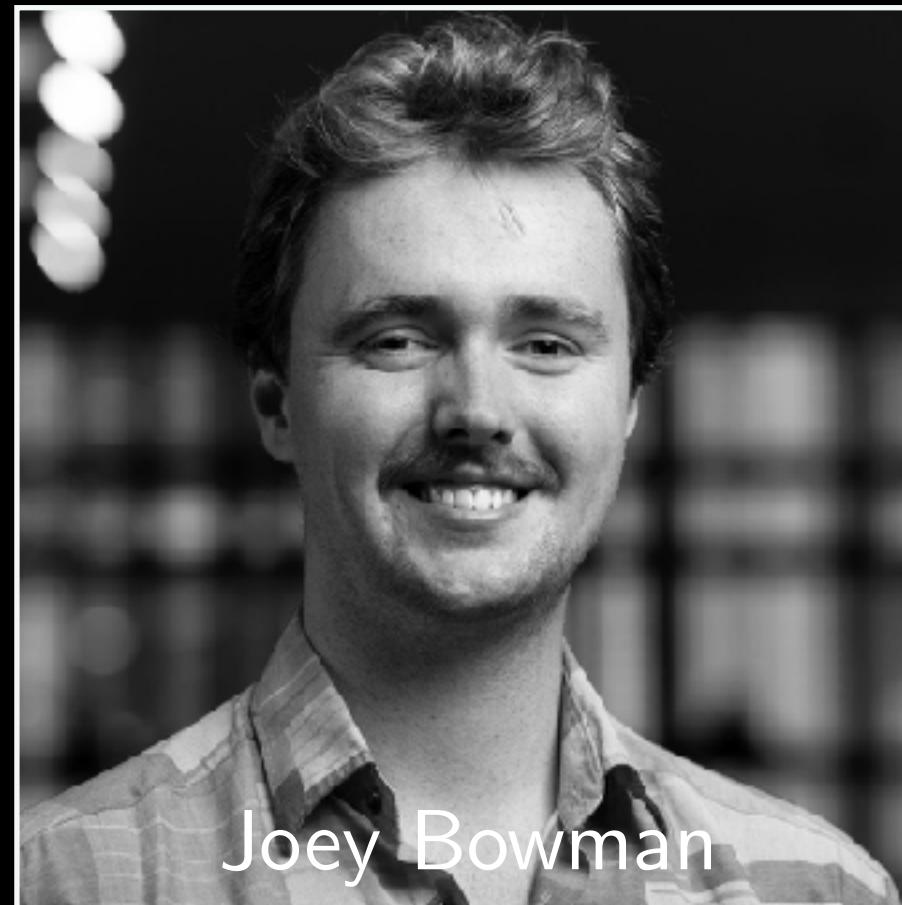
CELEBRATING
THE FIRST DECADE

OF GRAVITATIONAL
WAVE ASTRONOMY

Organized by
the NBI LIGO Group



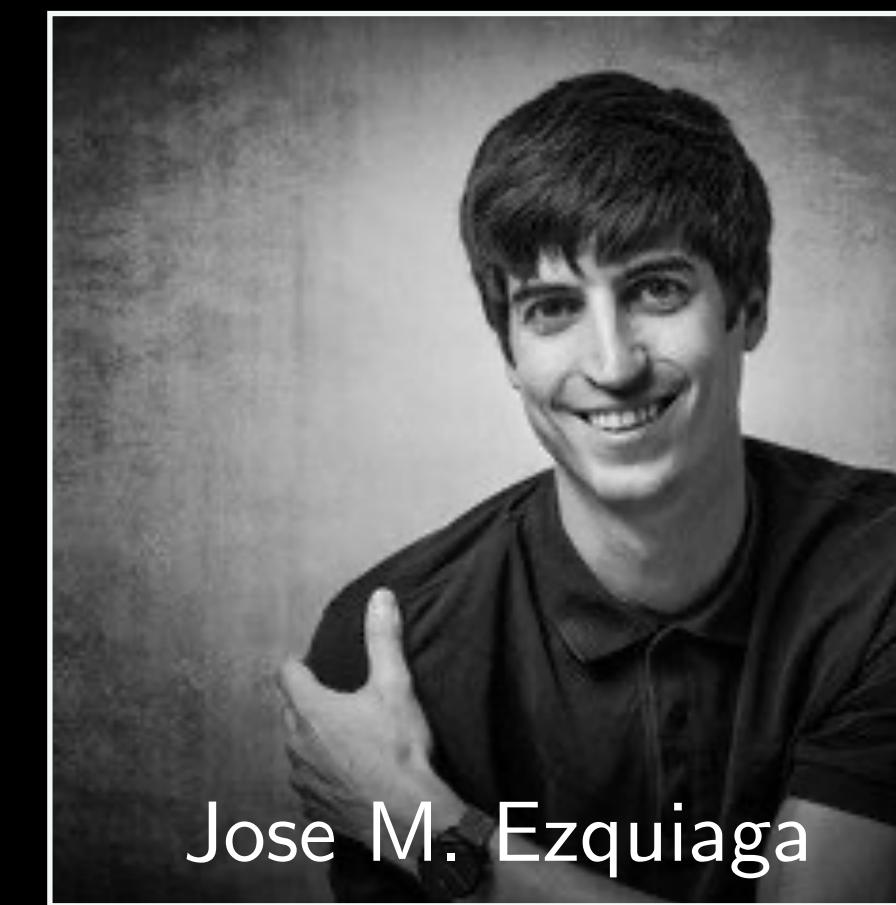
NBI LIGO group



Joey Bowman



Juno Chan



Jose M. Ezquiaga



Asta Heinesen



Rico Lo



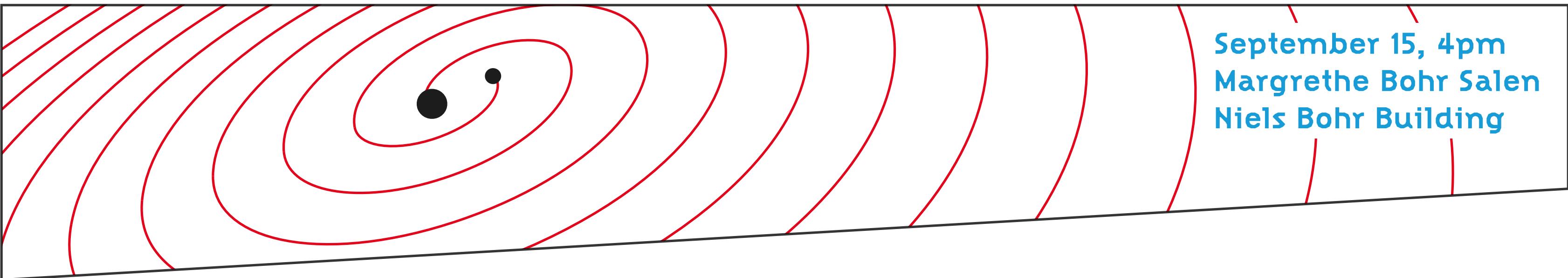
Lorena Magaña



Simon Maenaut



Luka Vujeva



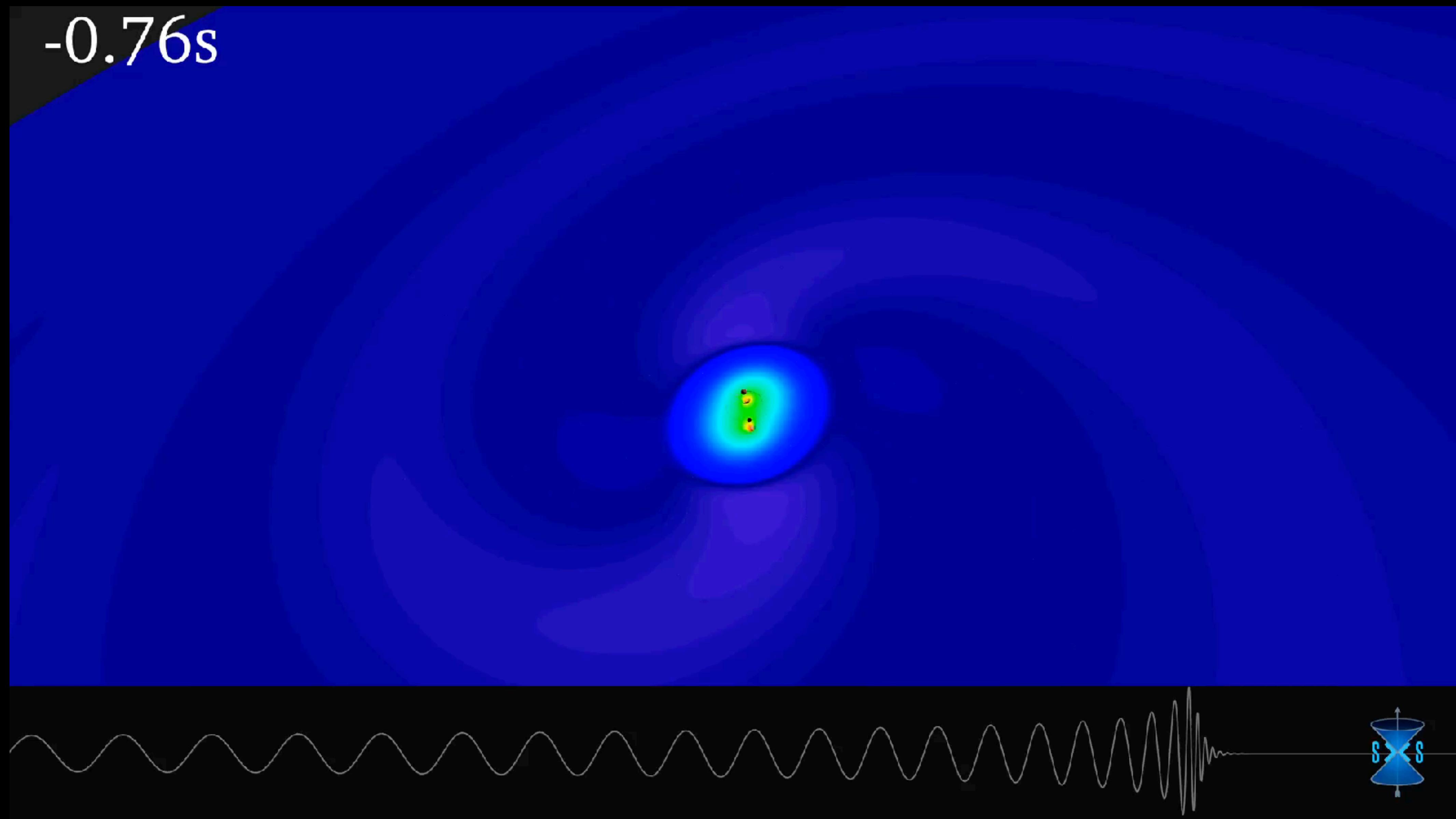
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This adventure started more than a billion years ago...

Gravitational waves are new cosmic messengers

Numerical simulation of a binary black hole merger

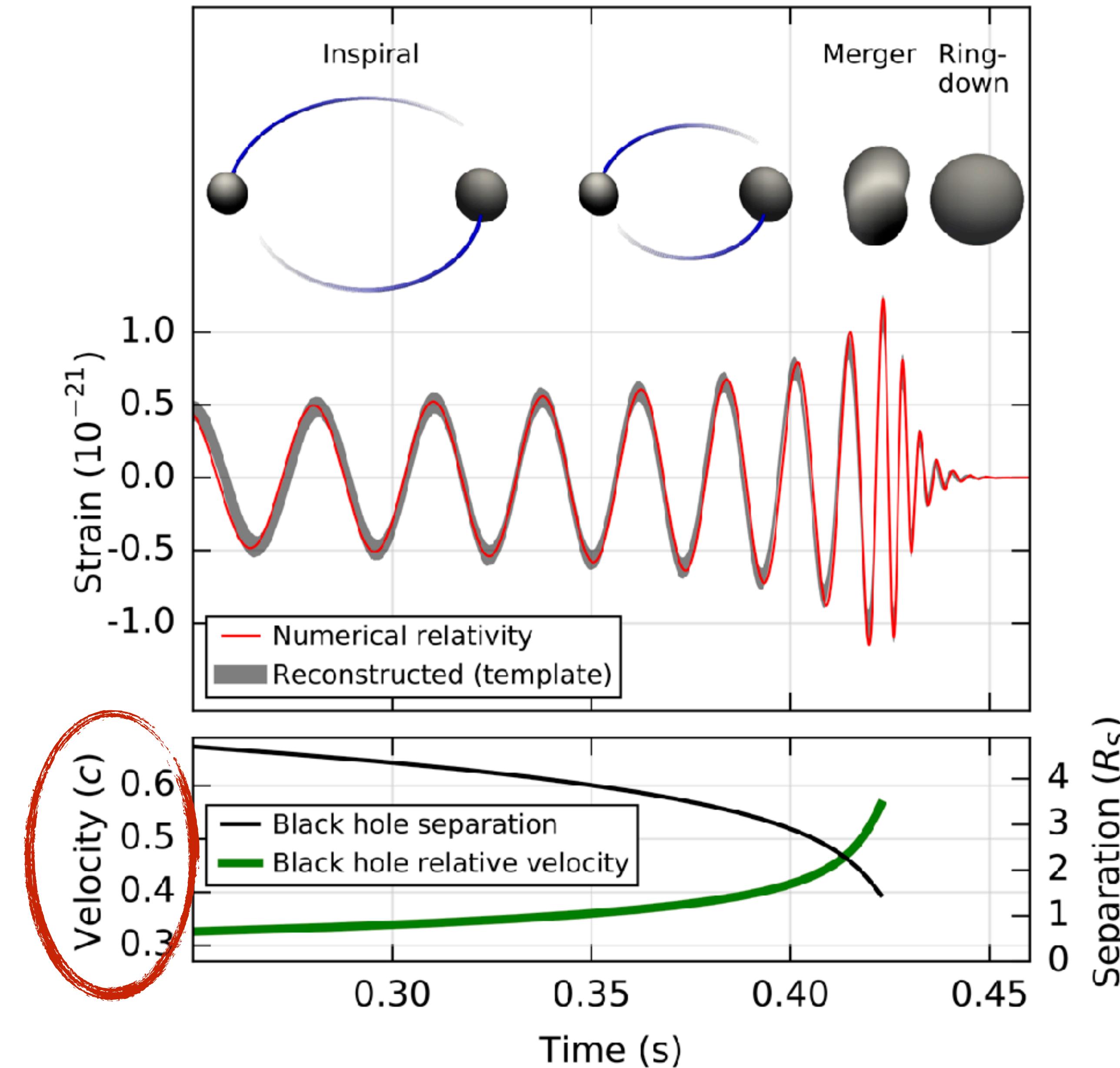
-0.76s



[Credit: SxS Collaboration]

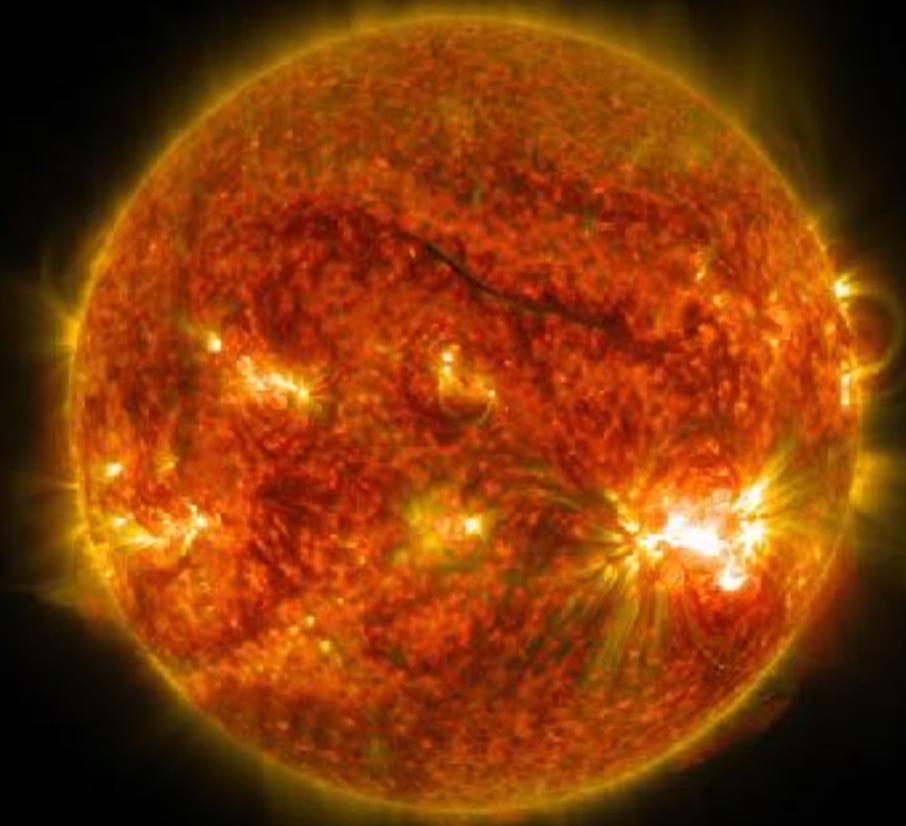
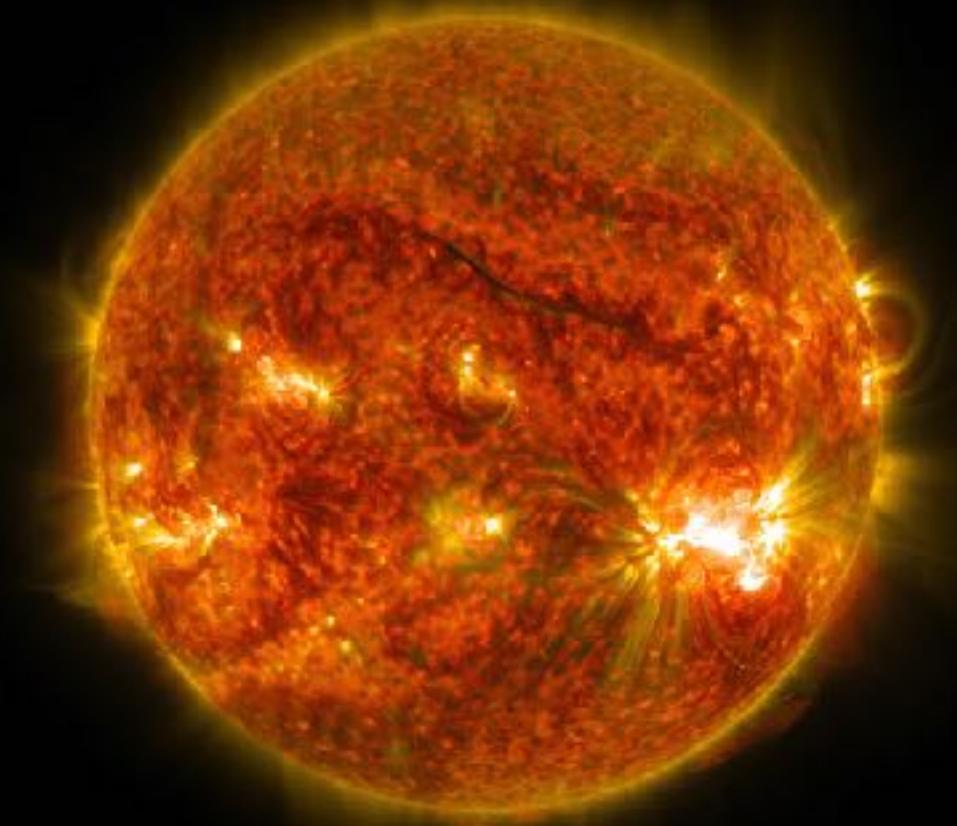
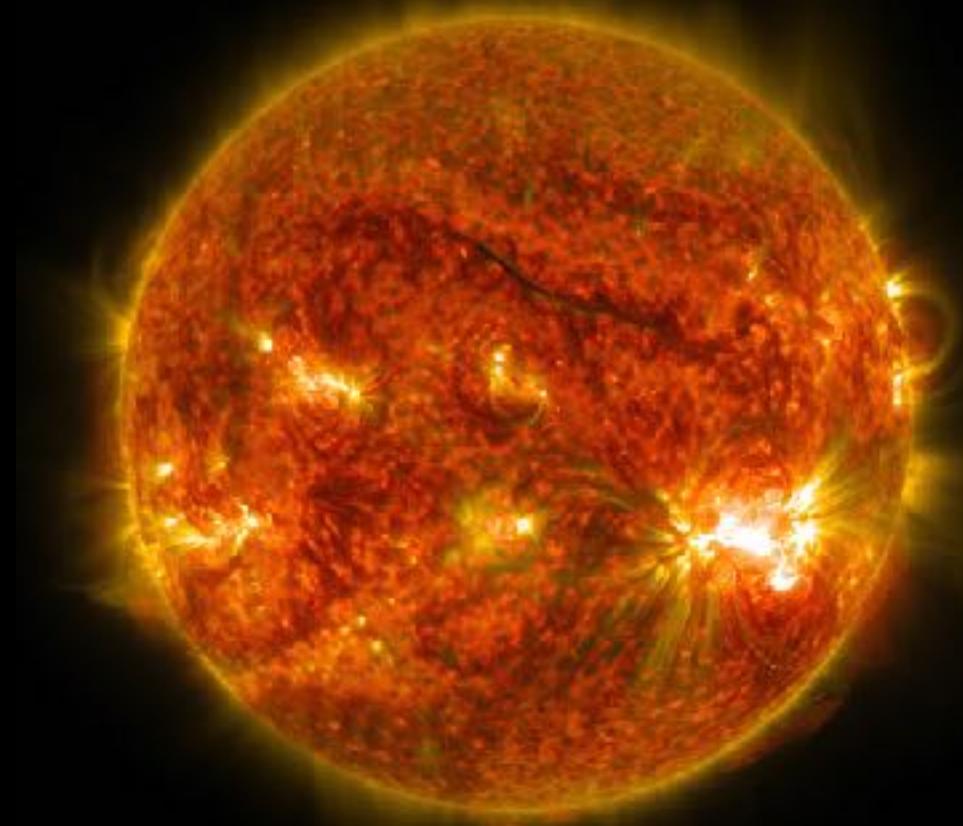
Gravitational waves from stellar-mass **binary black holes**

Strong-field gravity



Energy emitted in gravitational waves

=



>



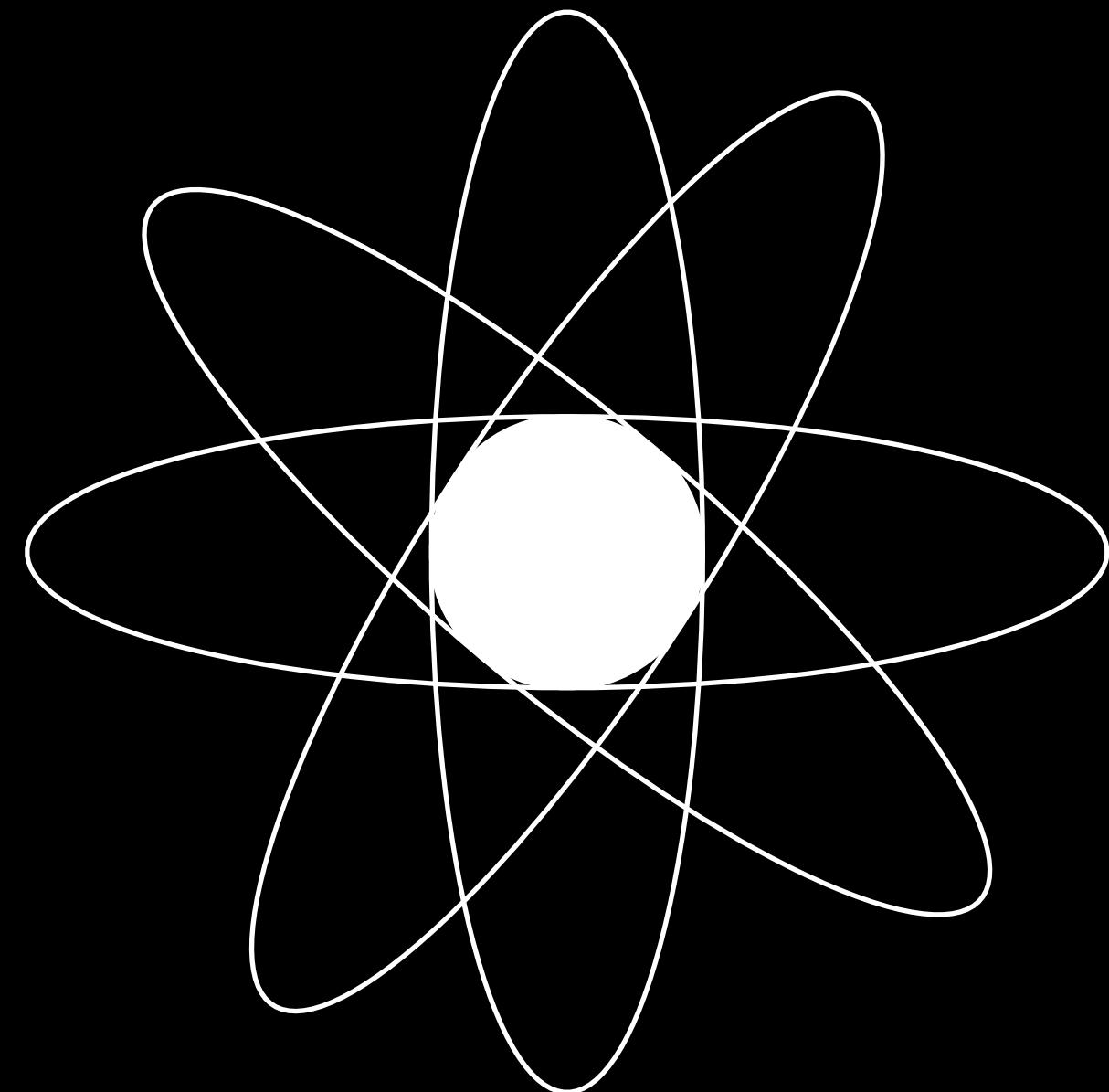
How large is the effect?



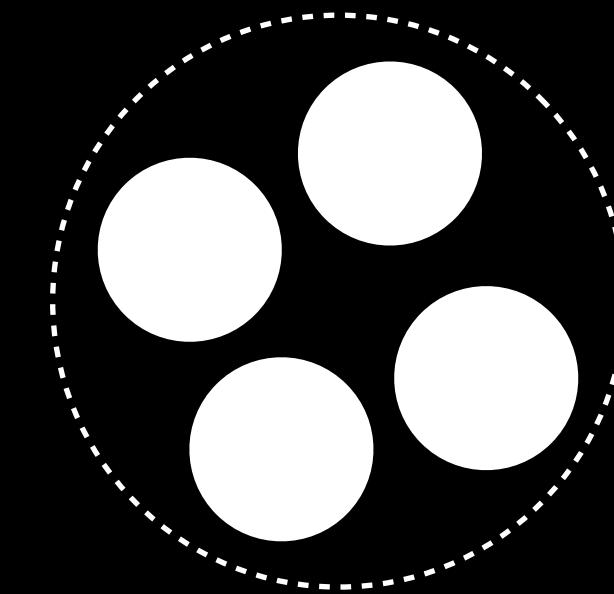
[Credit: R. Hurt, Caltech/MIT/LIGO Lab]

The variation in the distance at the detector is minuscule

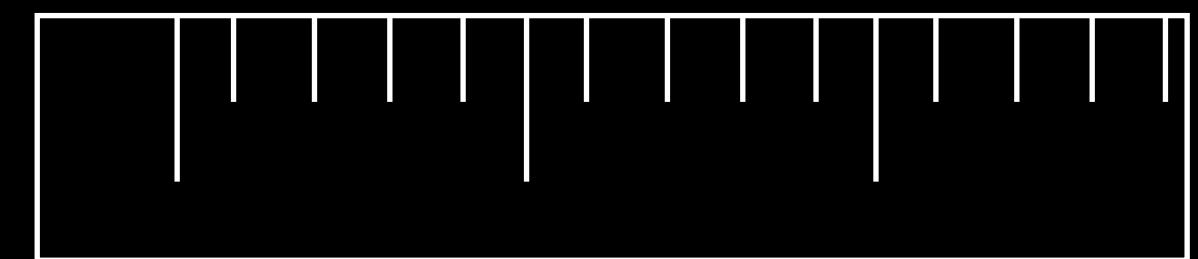
0.0000000000000001 meters



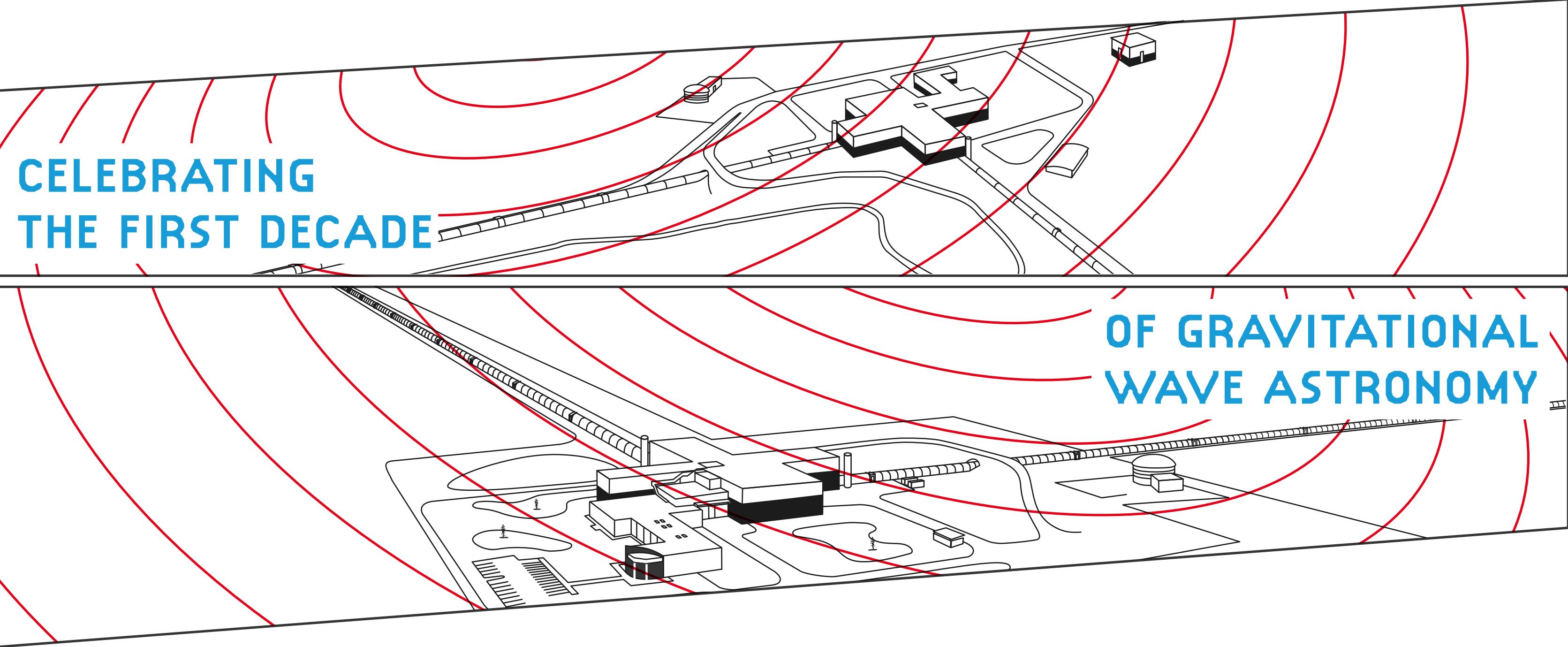
atom: 10^{-10} meters



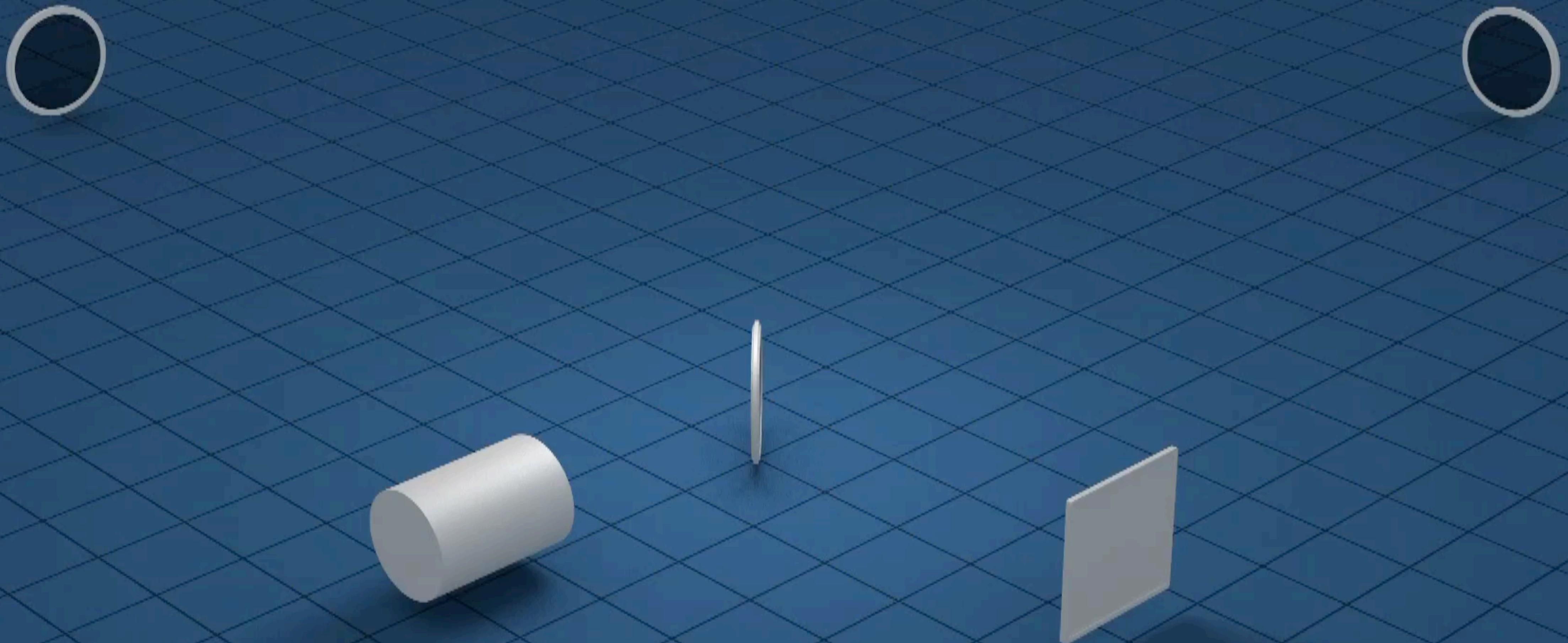
nucleus: 10^{-15} meters

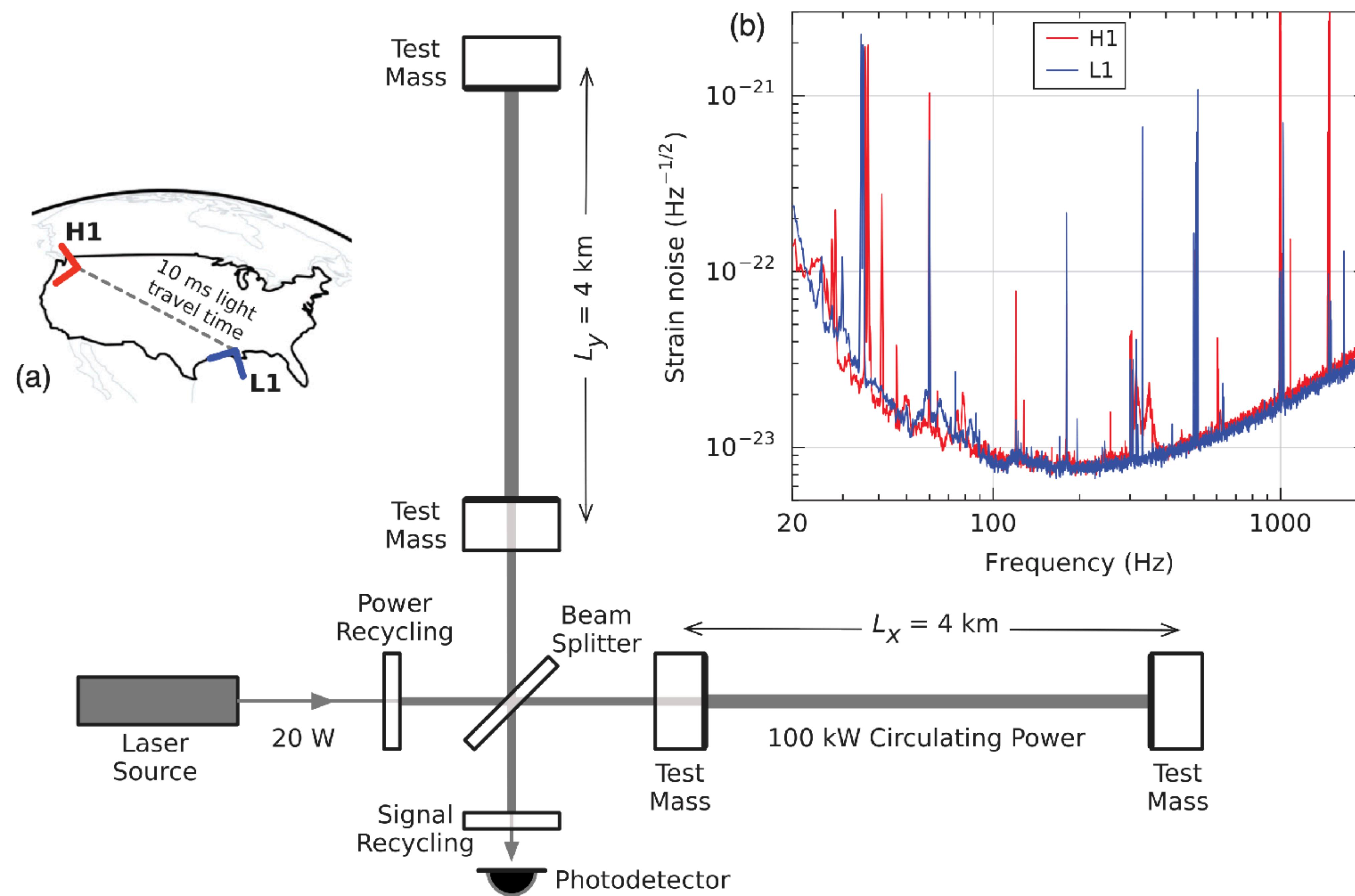


GW effect: 10^{-18} meters



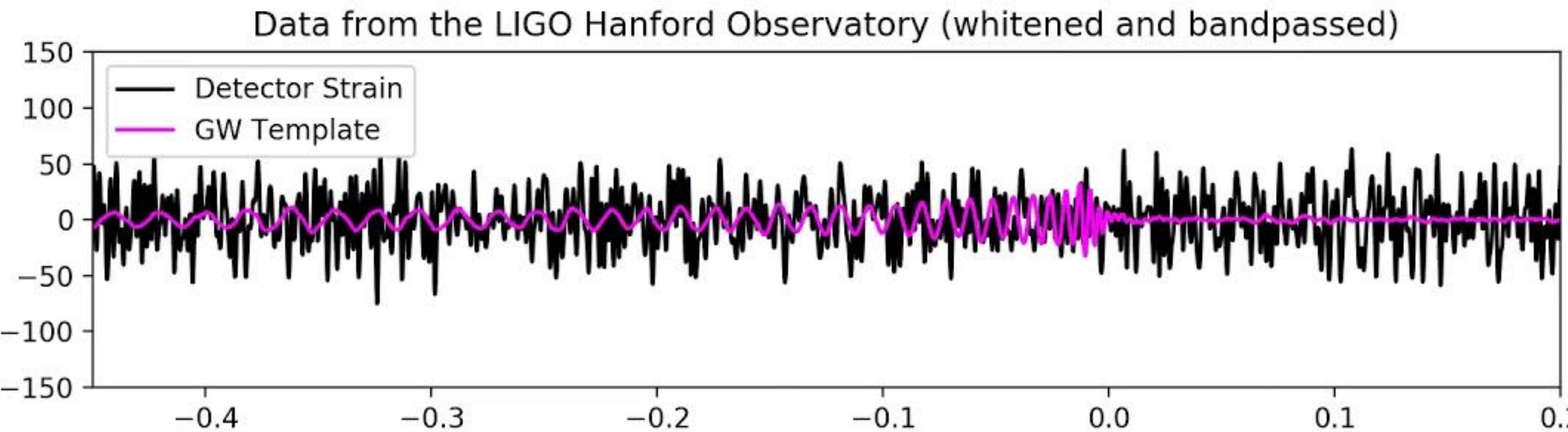
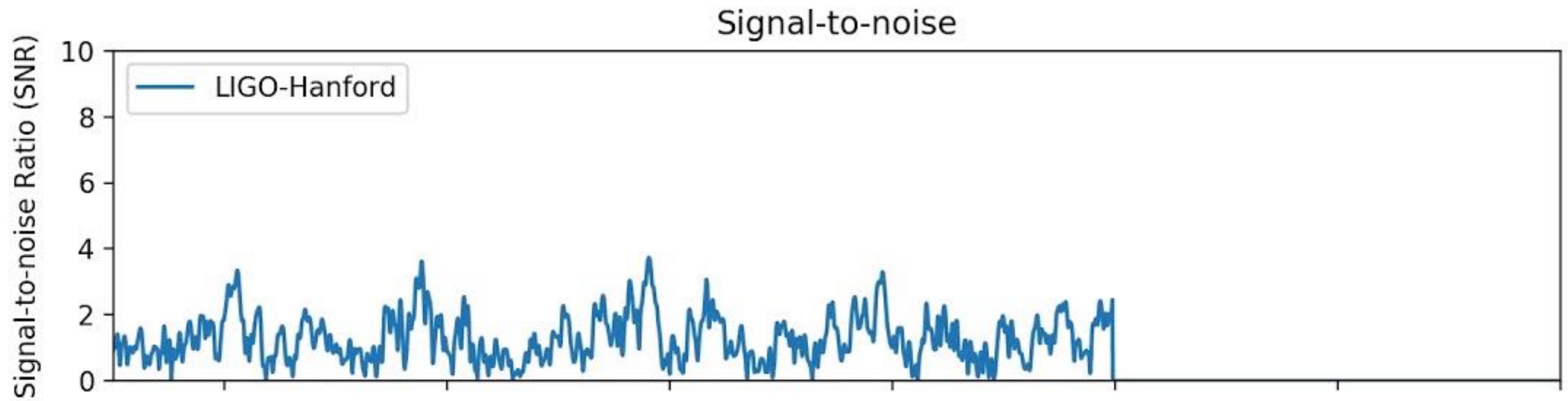
Laser Interferometer Gravitational-wave Observatory (LIGO)

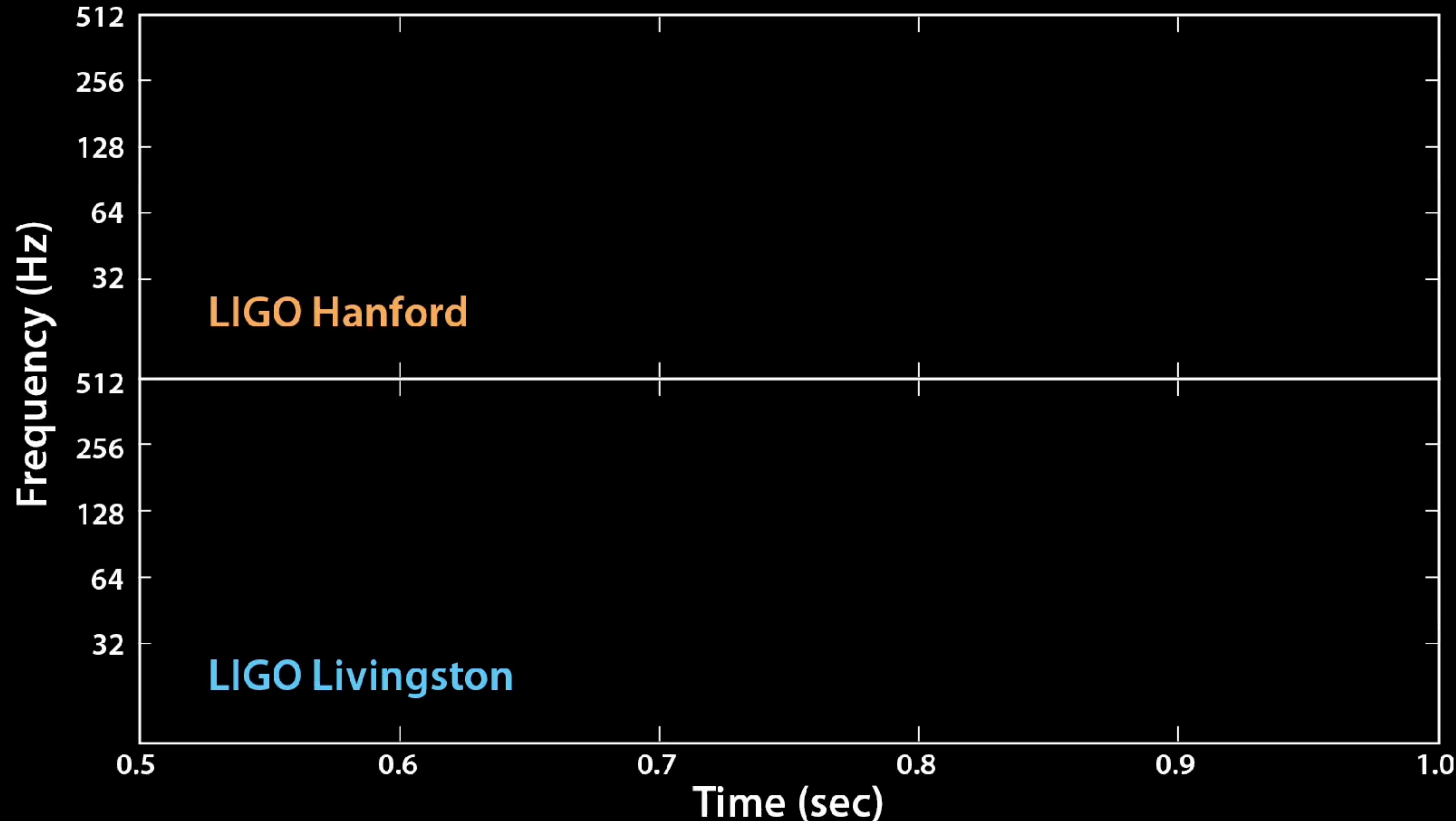




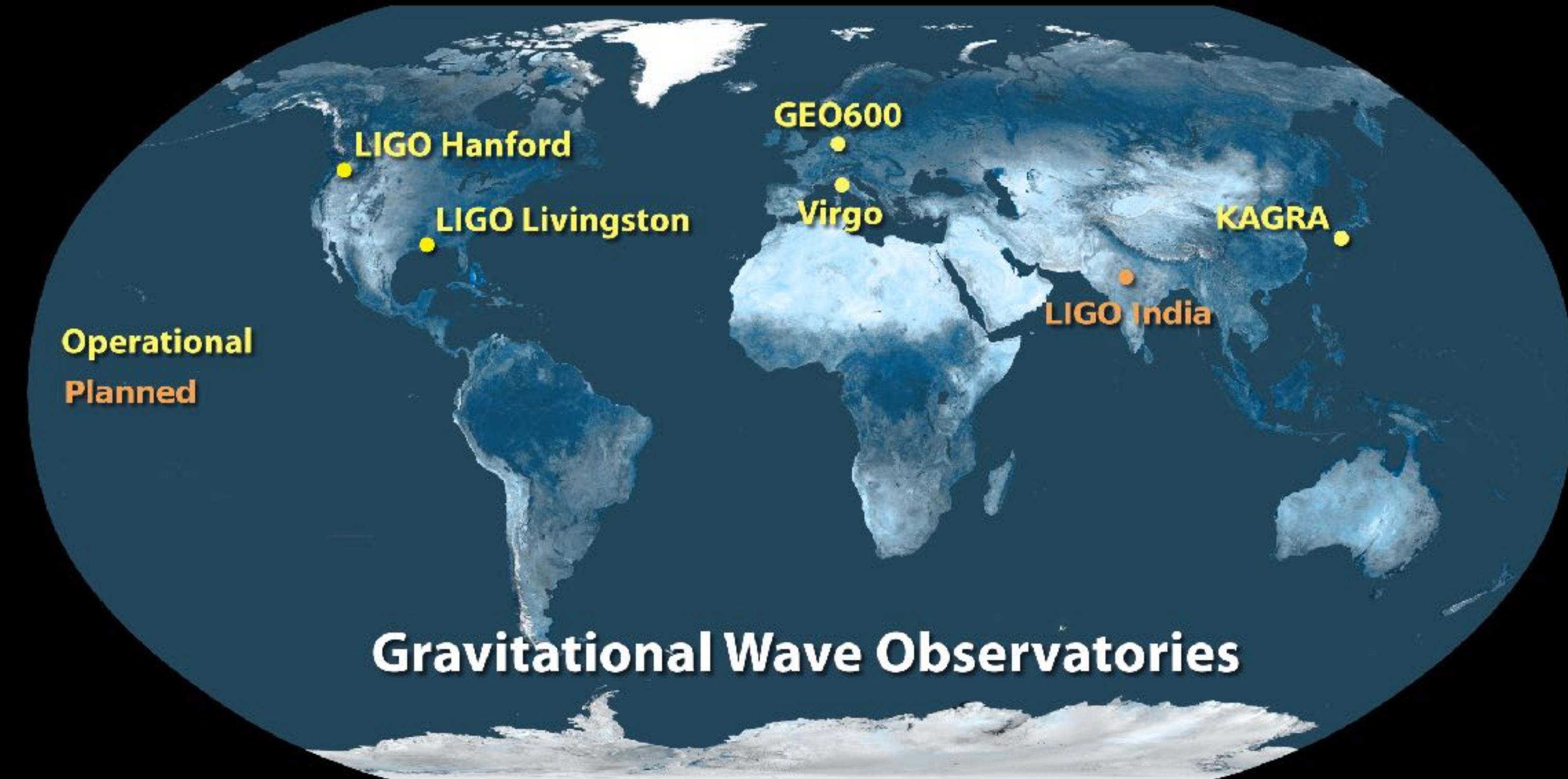
[Credit: LIGO]

Matched-filtering





A *global* gravitational wave detector network



[Hanford, US]



[Livingston, US]



[Virgo, Italy]



[KAGRA, Japan]



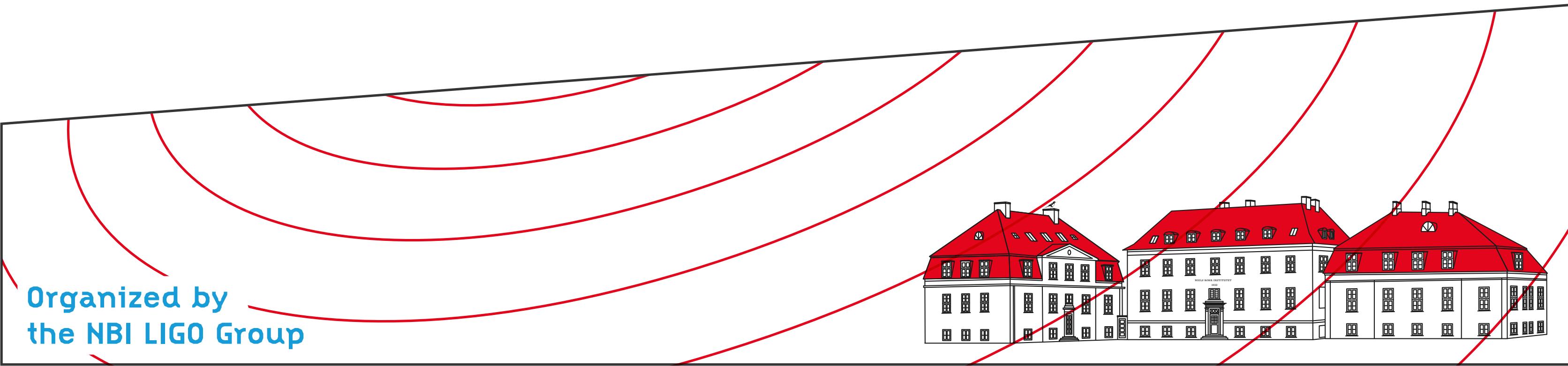
[Lorena @LIGO Livingston, 2015]



[Juno @Virgo, 2018]

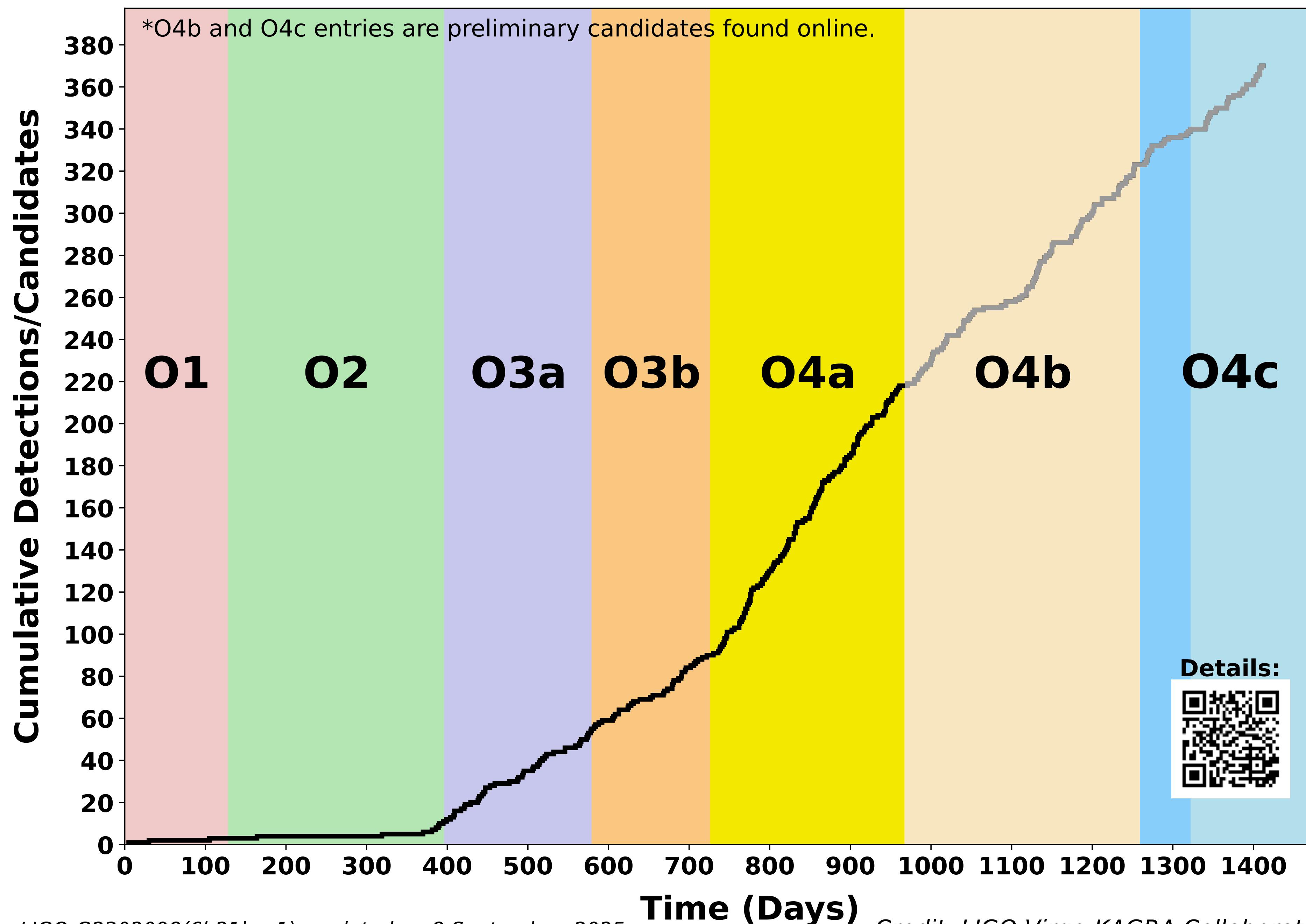


[Rico & Jose @KAGRA, 2023]



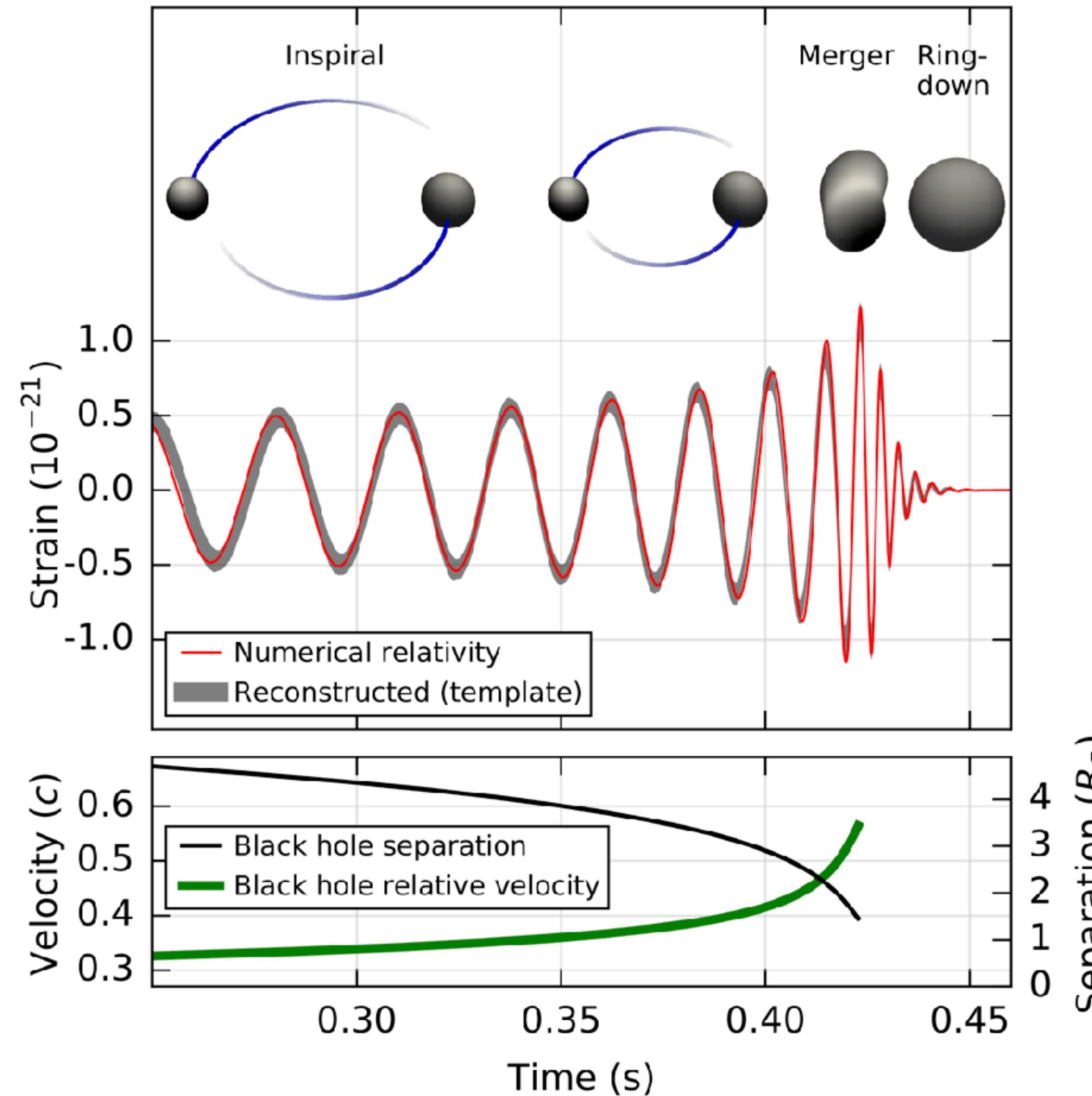
Organized by
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$$O1+O2+O3+O4a = 218, \ O4b^* = 105, \ O4c^* = 47, \ Total = 370$$

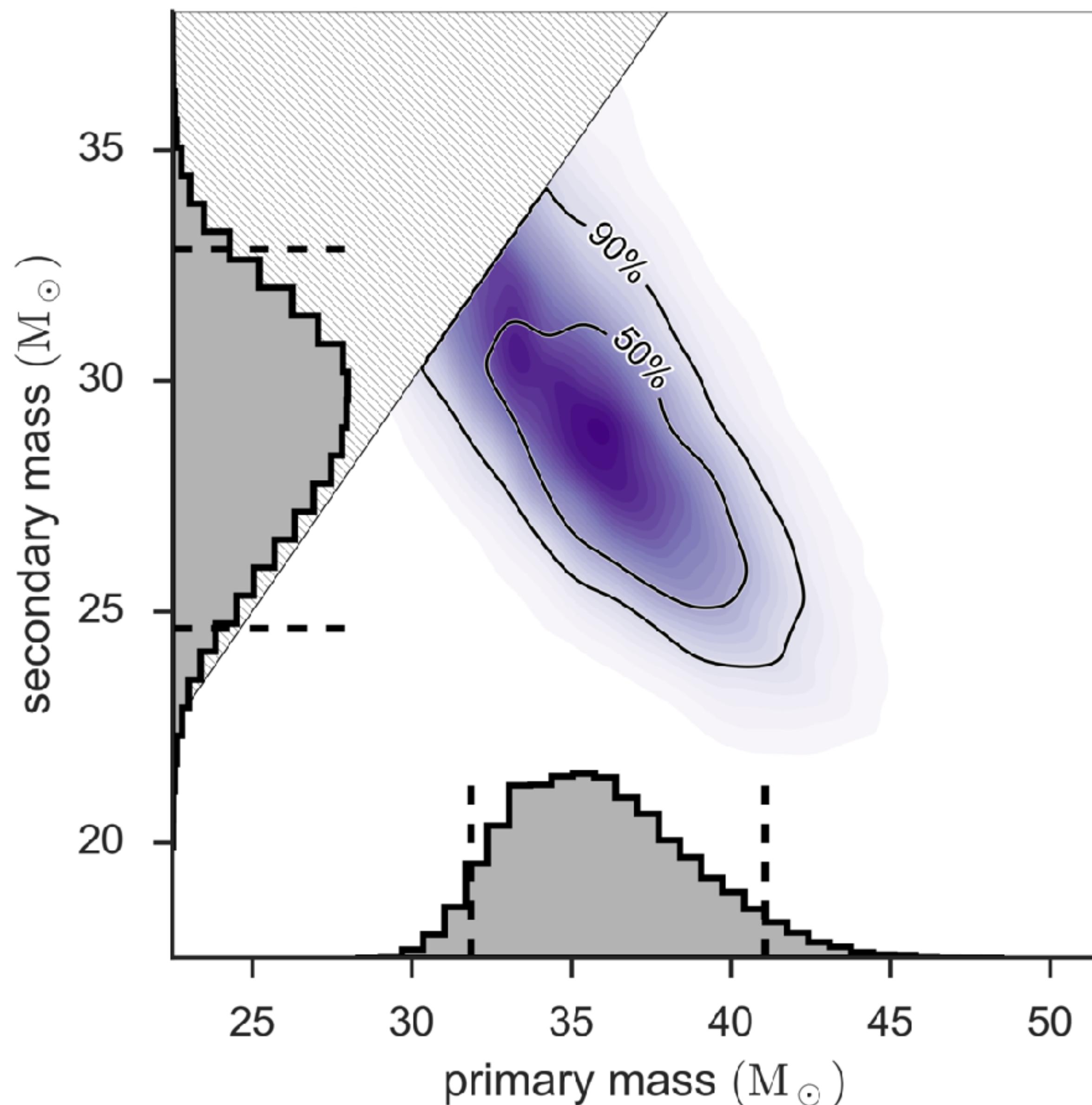


Gravitational wave phone numbers

GW150914: the first event!

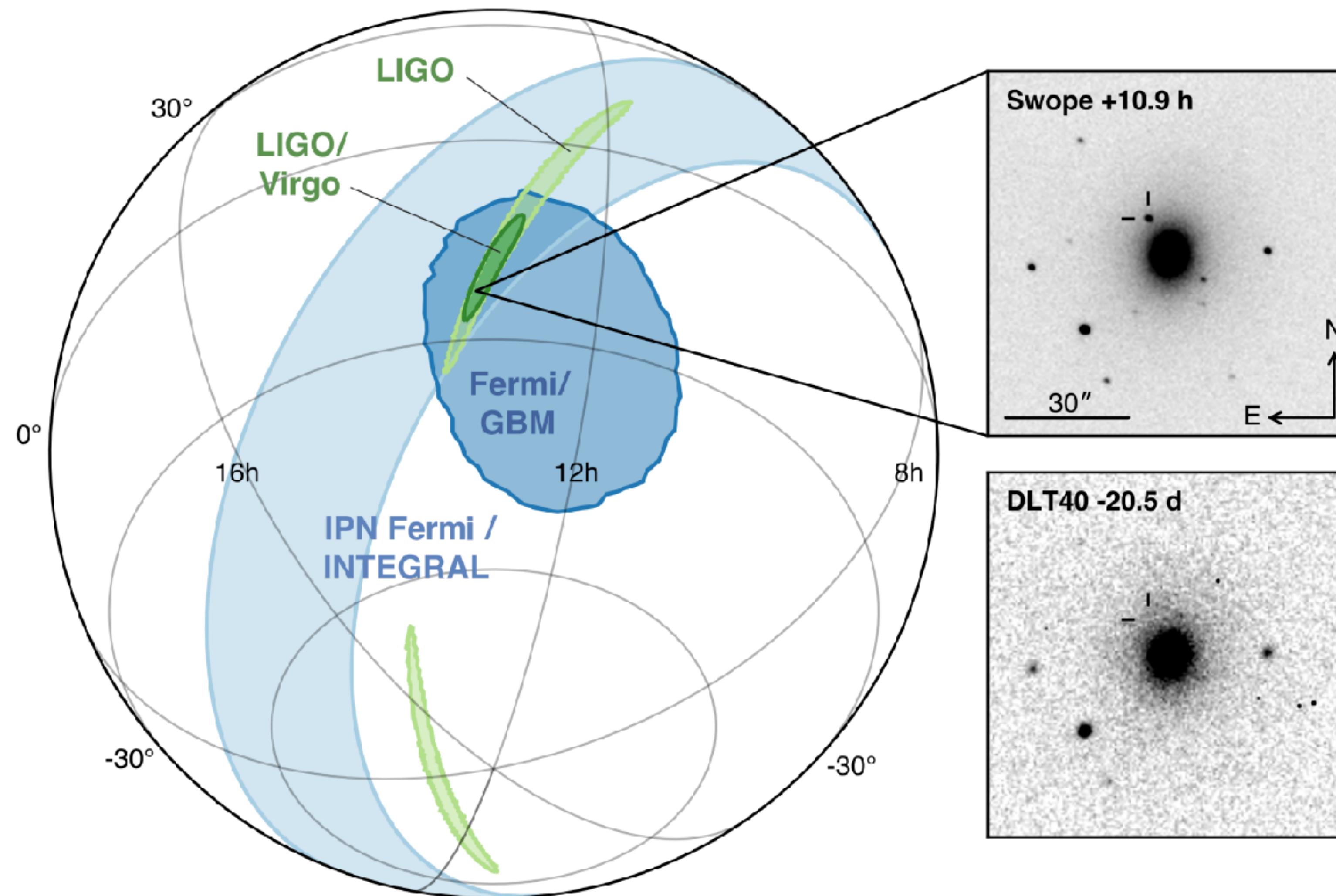


GW150914: learning about the signal properties!

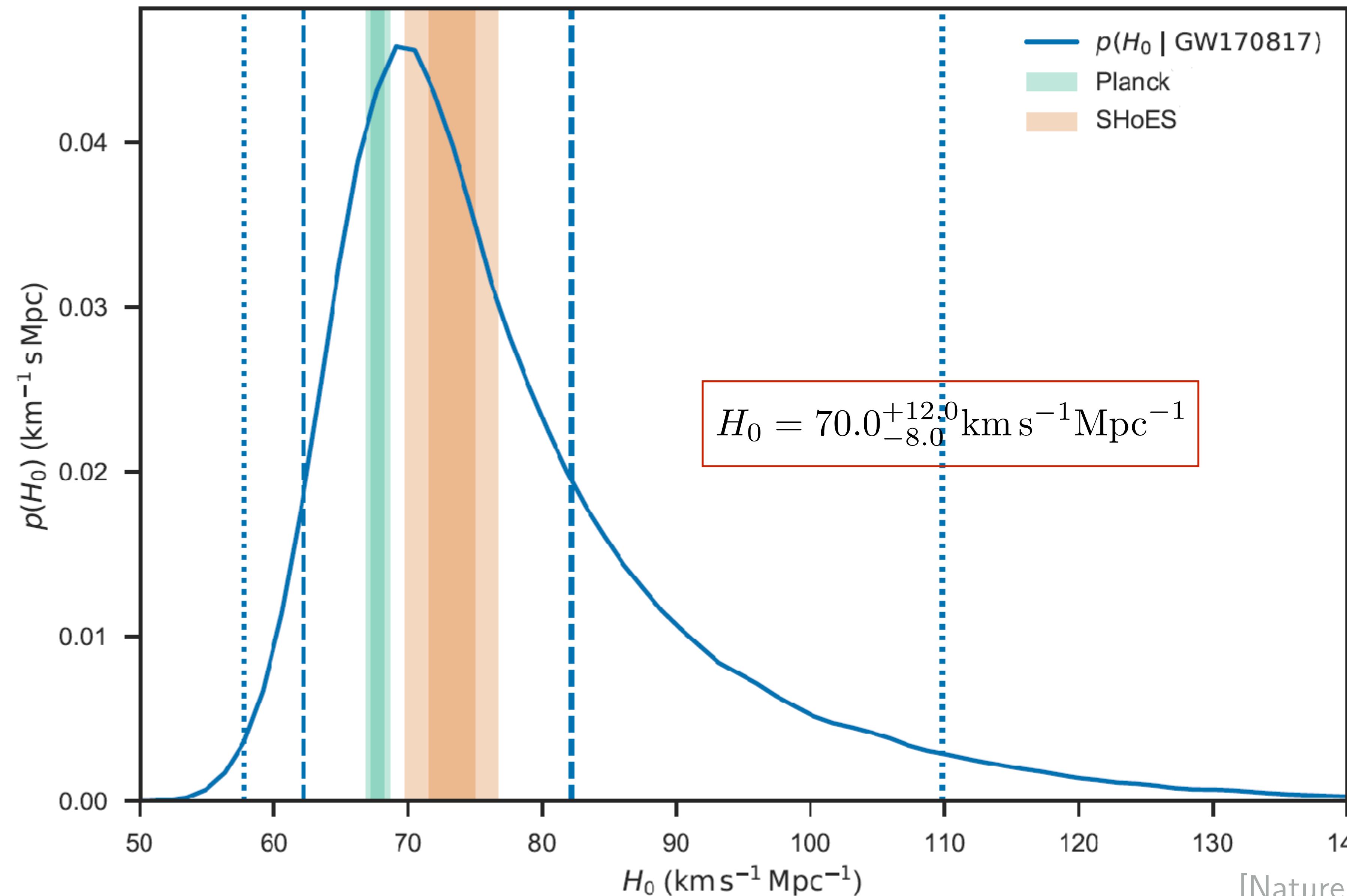


Binary neutron star mergers

GW170817: first multi-messenger event!



Gravitational waves are standard sirens



1	H
3	Li
4	Be
11	Na
12	Mg
19	K
20	Ca
21	Sc
22	Ti
23	V
24	Cr
25	Mn
26	Fe
27	Co
28	Ni
29	Cu
30	Zn
31	Ga
32	Ge
33	As
34	Se
35	Br
36	Kr
37	Rb
38	Sr
39	Y
40	Zr
41	Nb
42	Mo
43	Tc
44	Ru
45	Rh
46	Pd
47	Ag
48	Cd
49	In
50	Sn
51	Sb
52	Te
53	I
54	Xe
55	Cs
56	Ba
72	Hf
73	Ta
74	W
75	Re
76	Os
77	Ir
78	Pt
79	Au
80	Hg
81	Tl
82	Pb
83	Bi
84	Po
85	At
86	Rn
87	Fr
88	Ra

Element Origins

2	He
5	B
6	C
7	N
8	O
9	F
10	Ne
13	Al
14	Si
15	P
16	S
17	Cl
18	Ar
31	Ga
32	Ge
33	As
34	Se
35	Br
36	Kr
49	In
50	Sn
51	Sb
52	Te
53	I
54	Xe

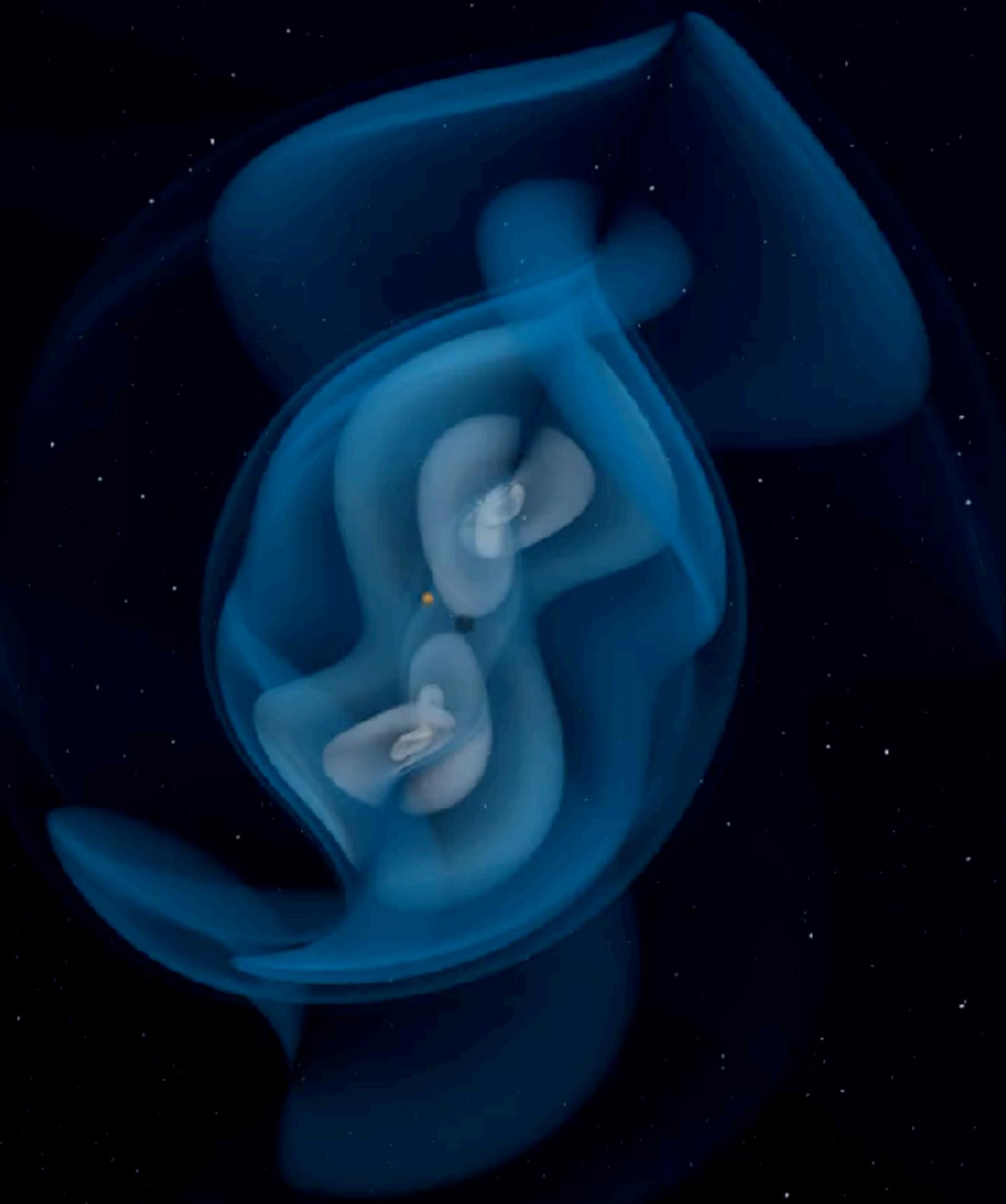
57	La
58	Ce
59	Pr
60	Nd
61	Pm
62	Sm
63	Eu
64	Gd
65	Tb
66	Dy
67	Ho
68	Er
69	Tm
70	Yb
71	Lu

Merging Neutron Stars
Dying Low Mass Stars

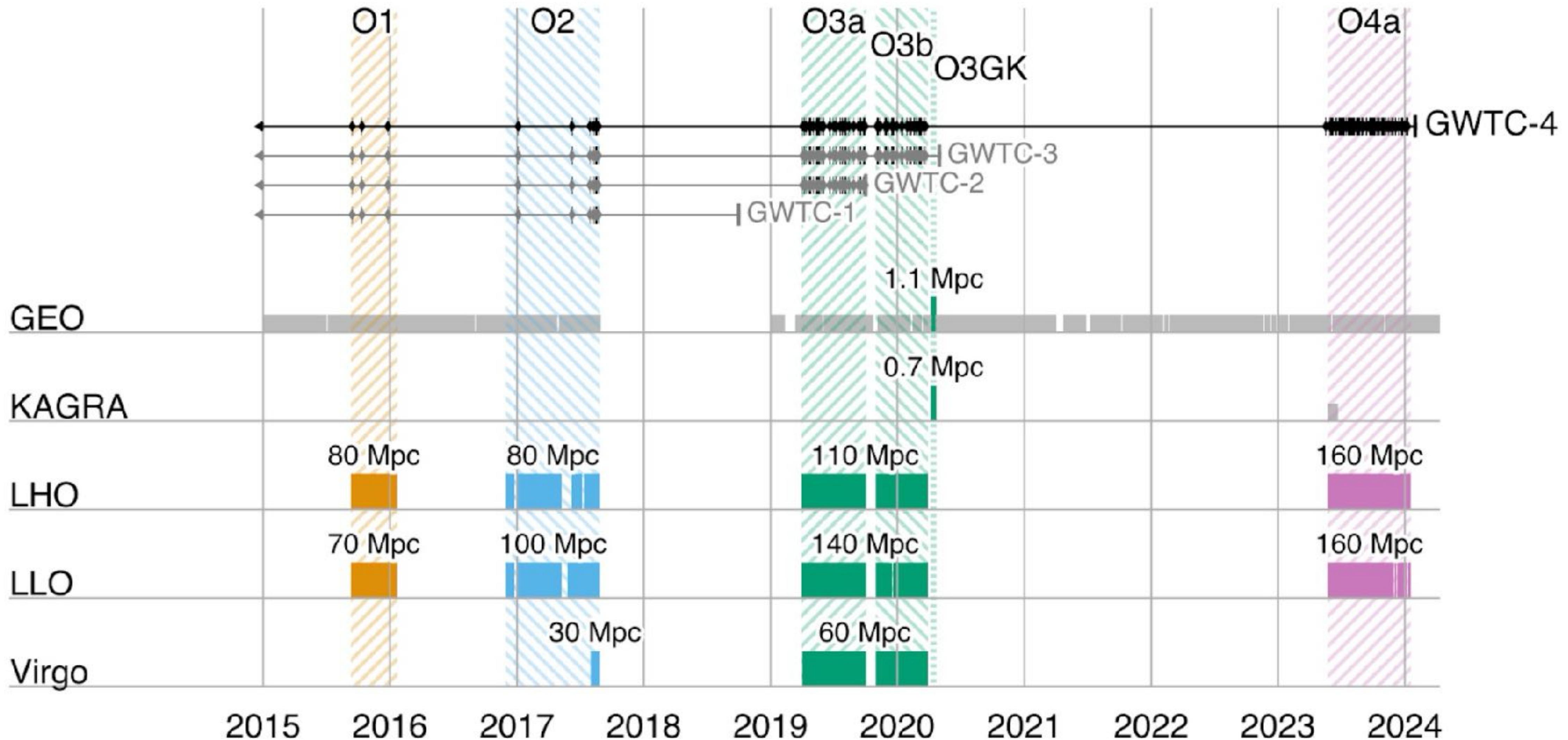
Exploding Massive Stars
Exploding White Dwarfs

Big Bang
Cosmic Ray Fission

Neutron star - black hole mergers

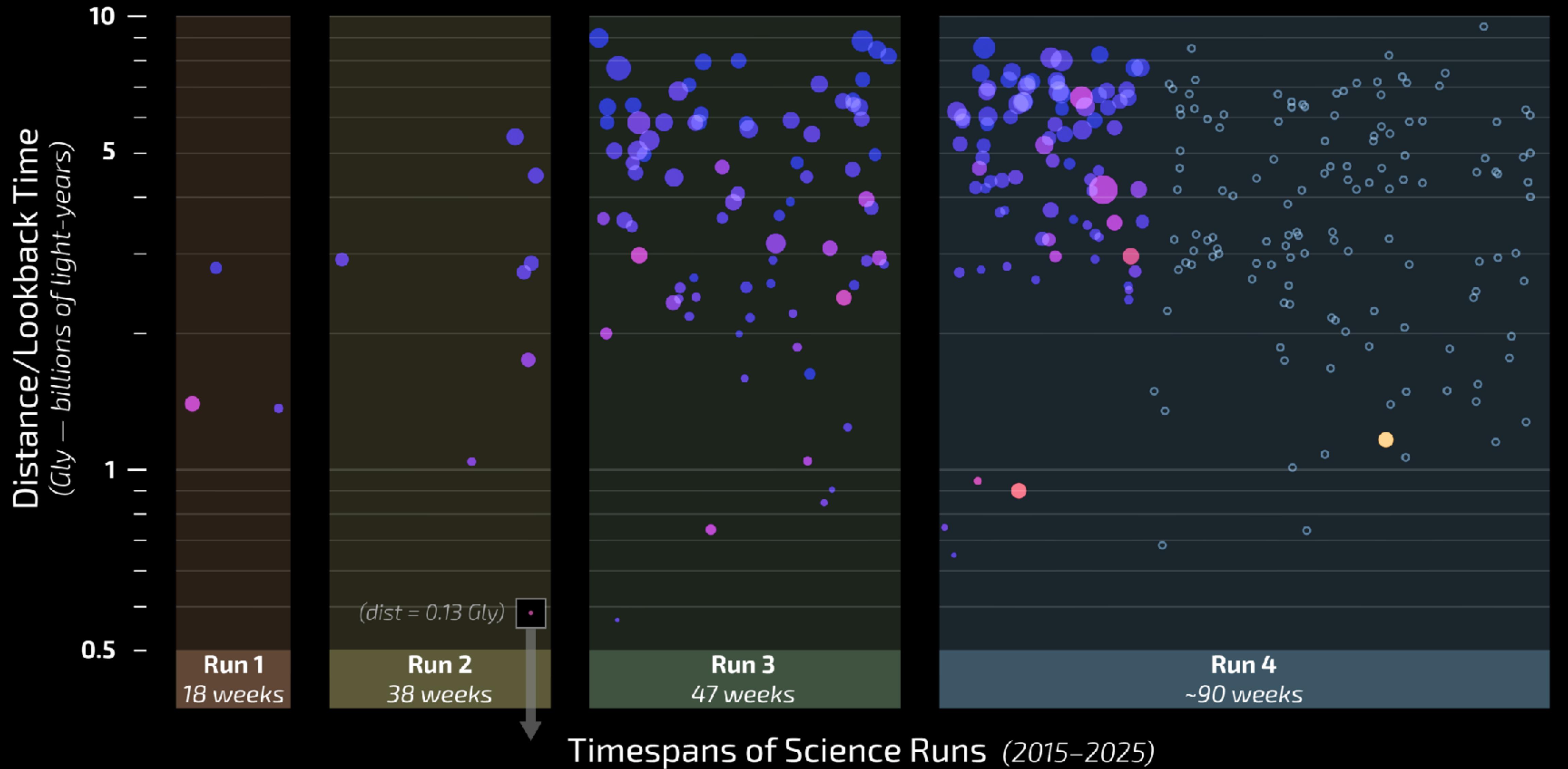


Gravitational Wave Transient Catalogs (GWTC)



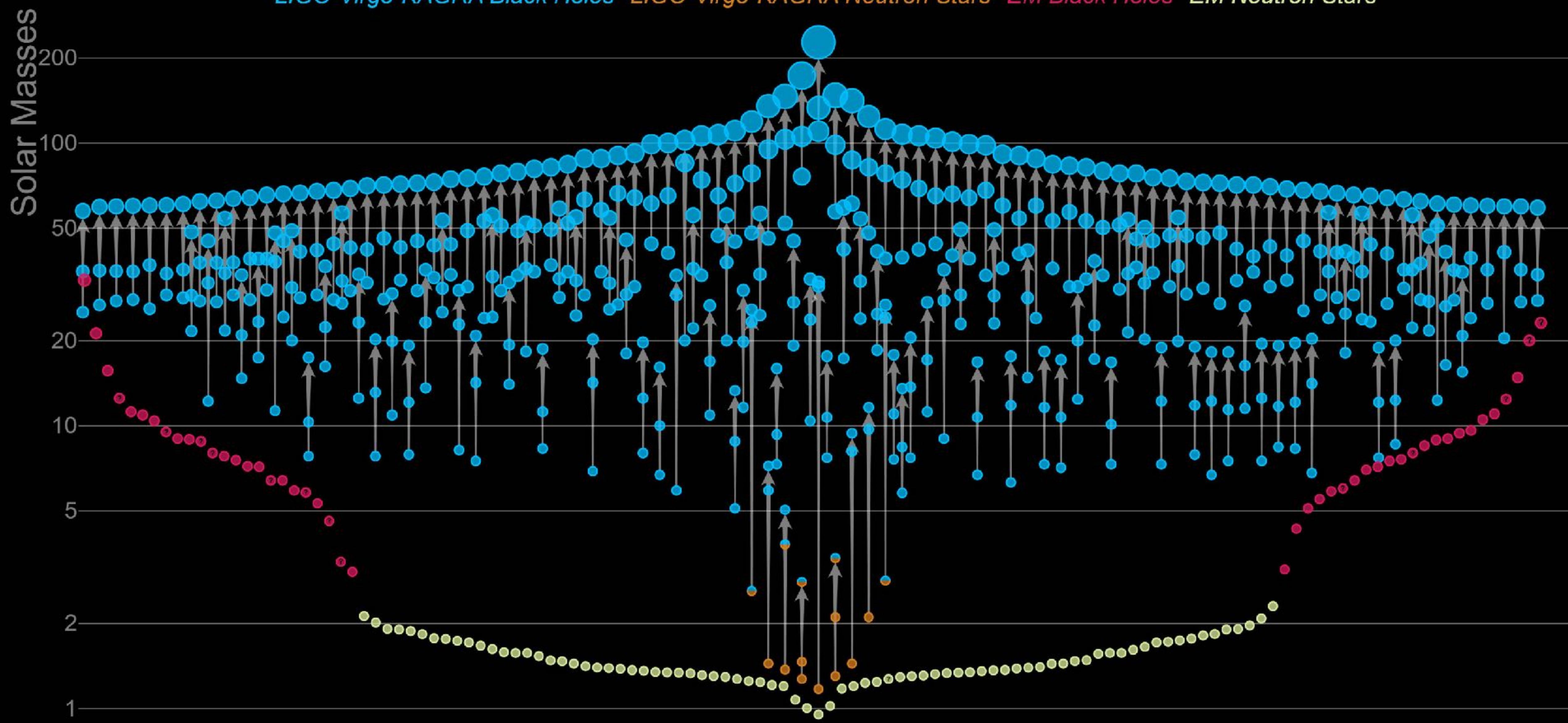
10 Years of LVK Black Hole* Mergers

*plus several neutron stars!

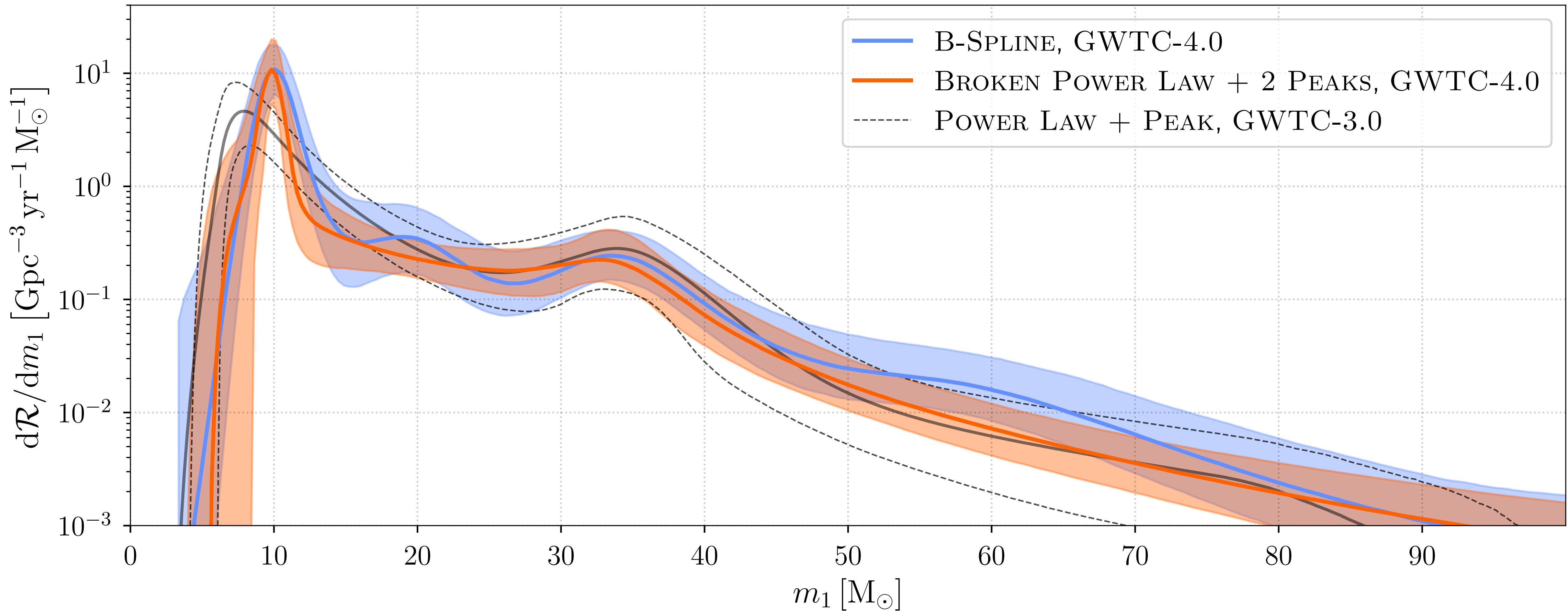


Masses in the Stellar Graveyard

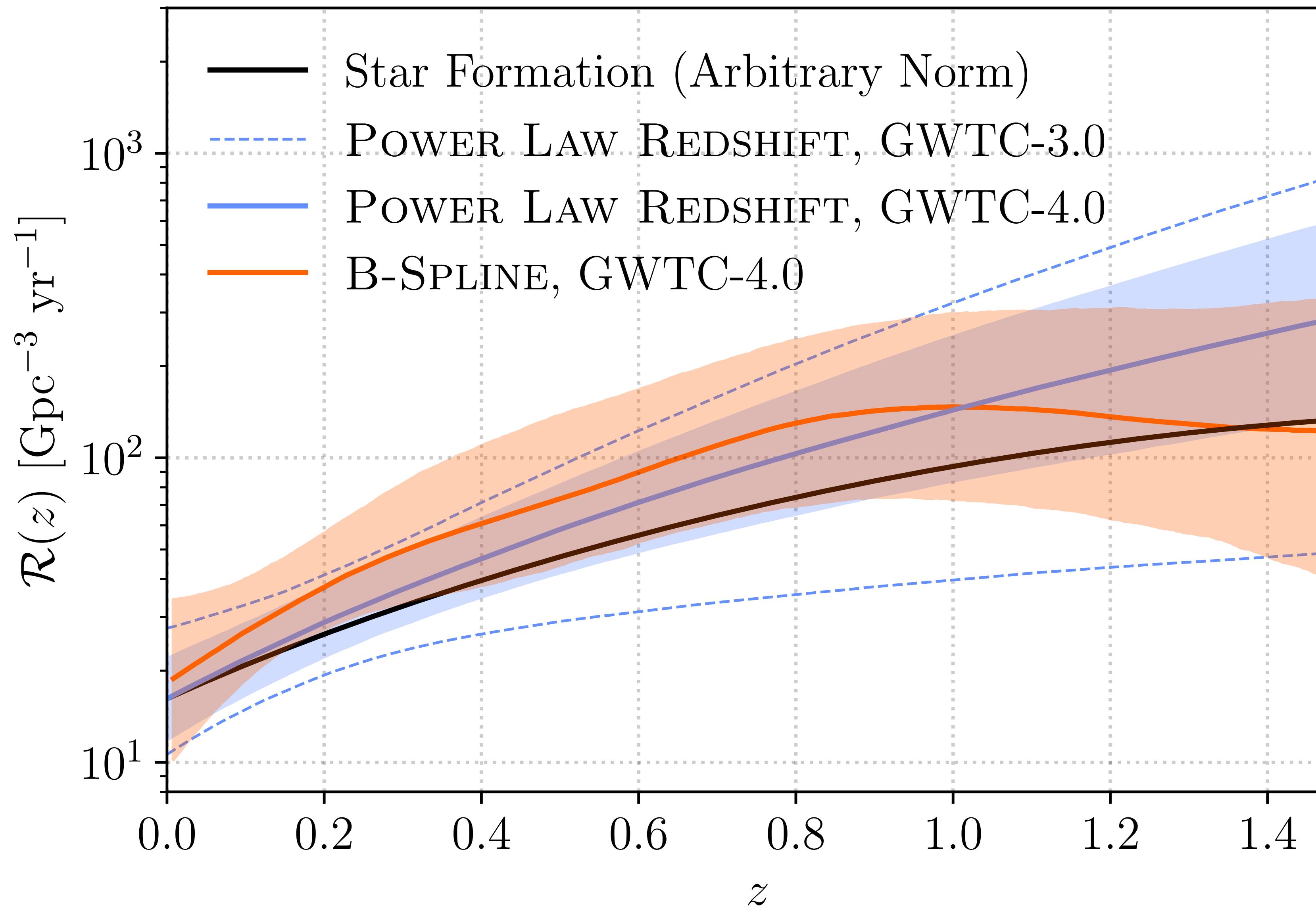
LIGO-Virgo-KAGRA Black Holes *LIGO-Virgo-KAGRA Neutron Stars* *EM Black Holes* *EM Neutron Stars*



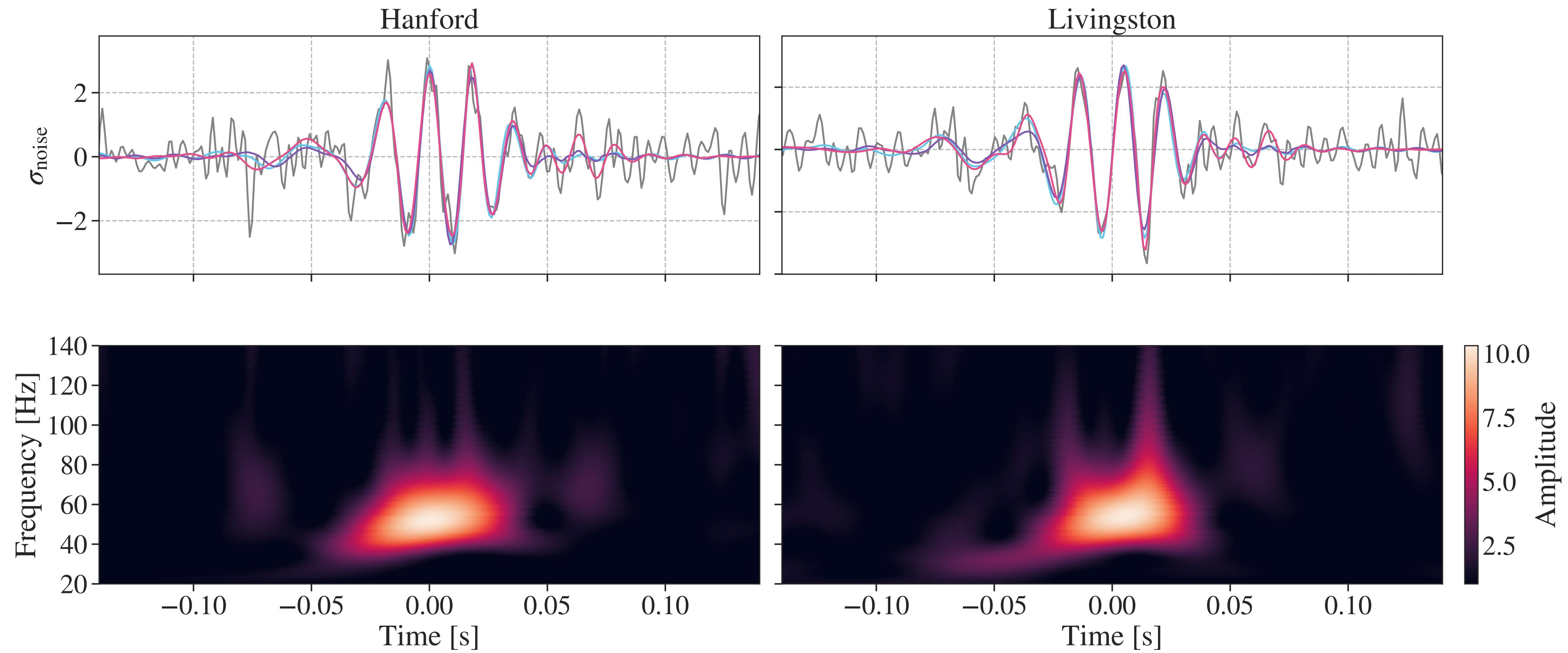
GWTC-4: black holes across the mass spectrum



GWTC-4: black holes across cosmic time



GW231123: the most massive black hole binary (*total mass* between 190 and 265 M_{sun}!)



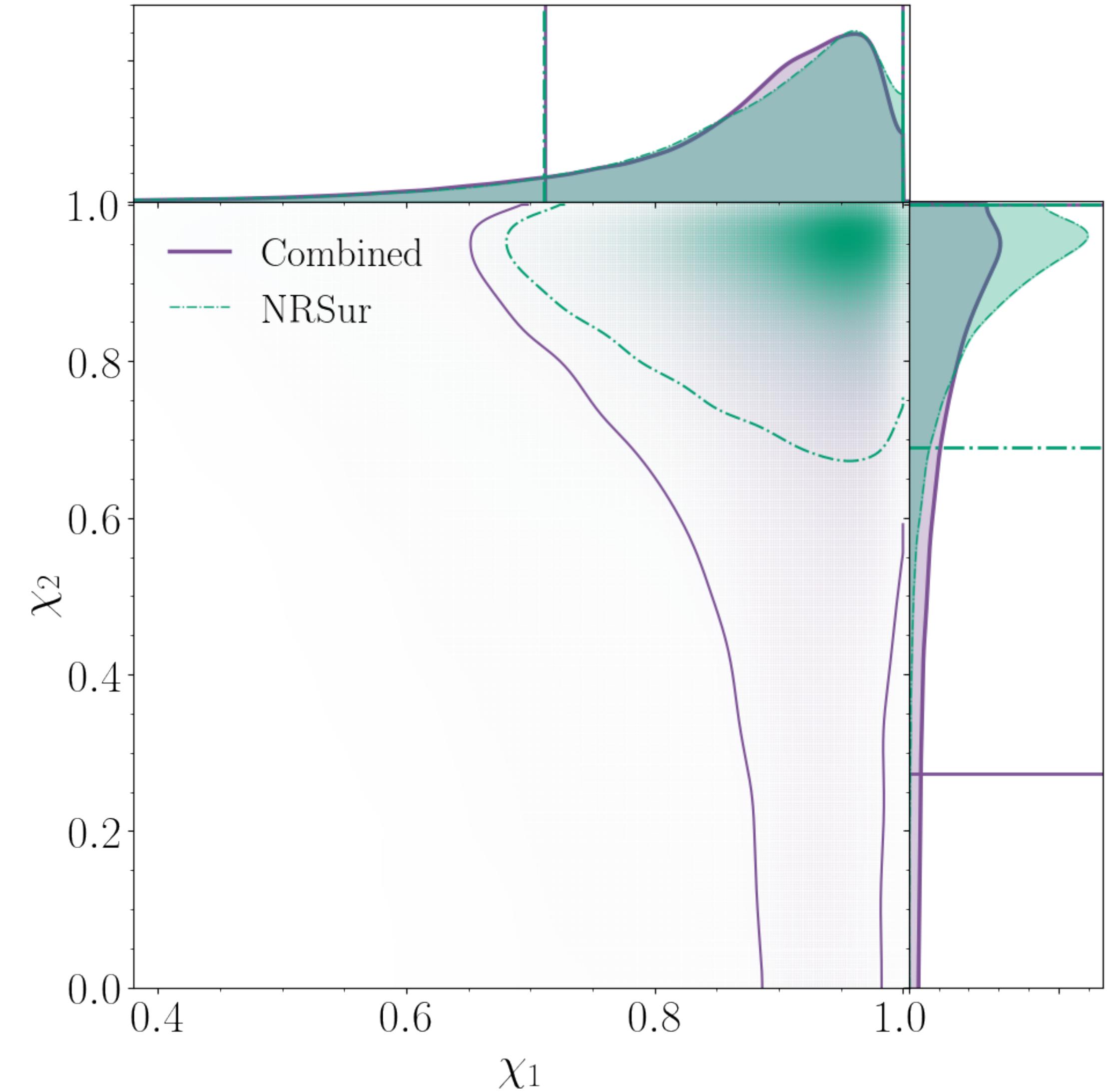
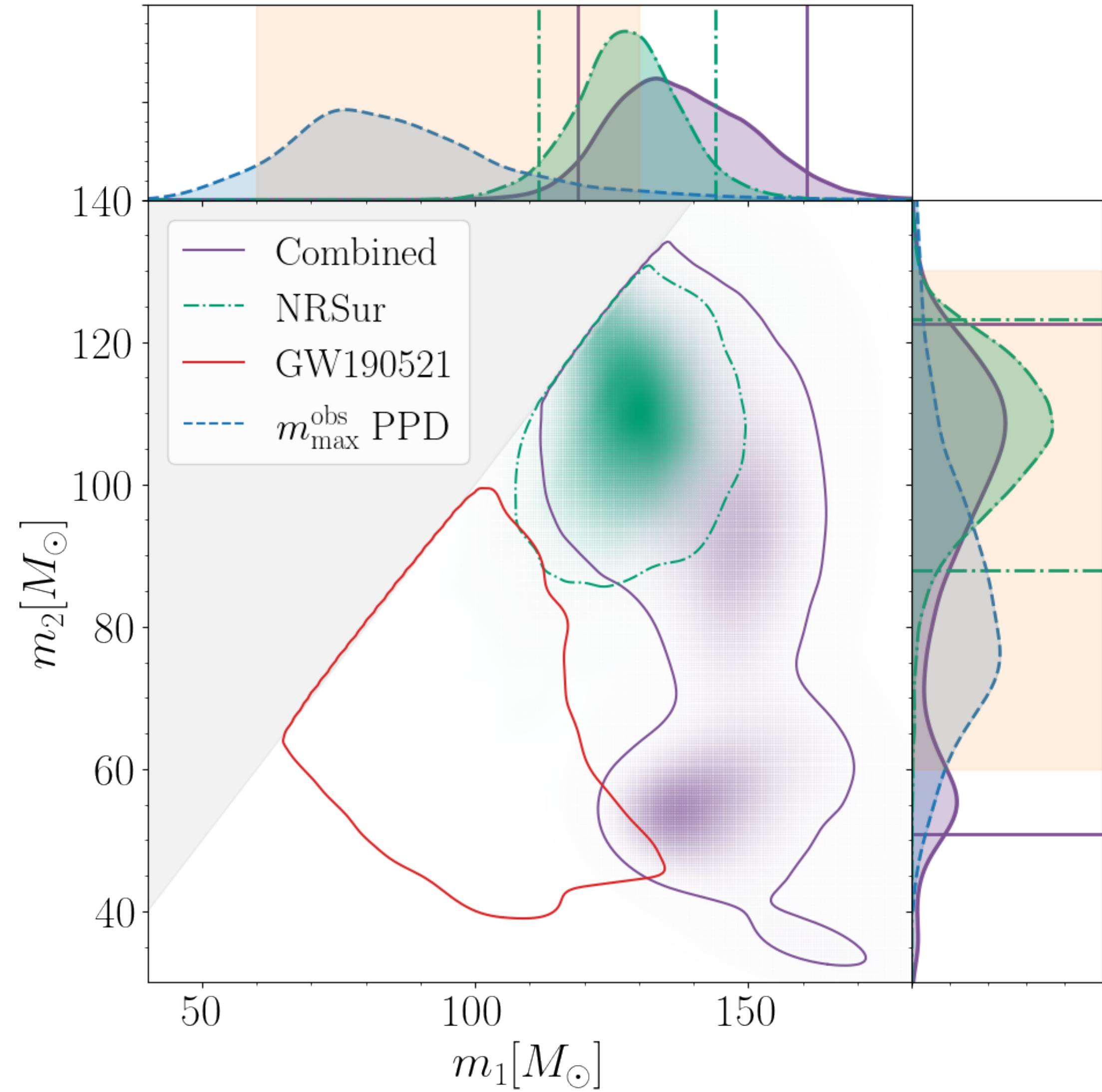
— Whitened data

■ BBH Template Reconstruction (Bilby)

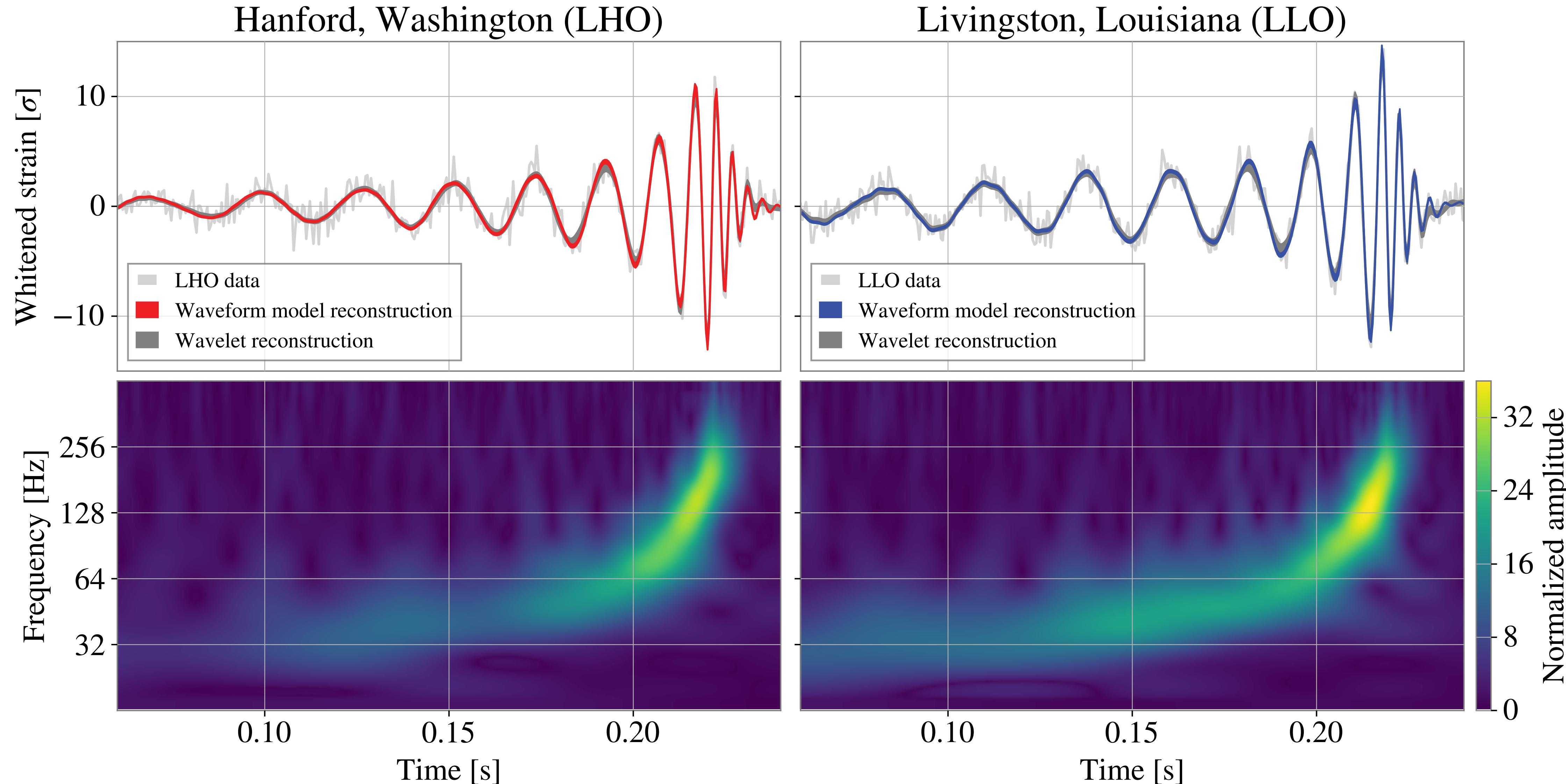
■ Wavelet Reconstruction (BayesWave)

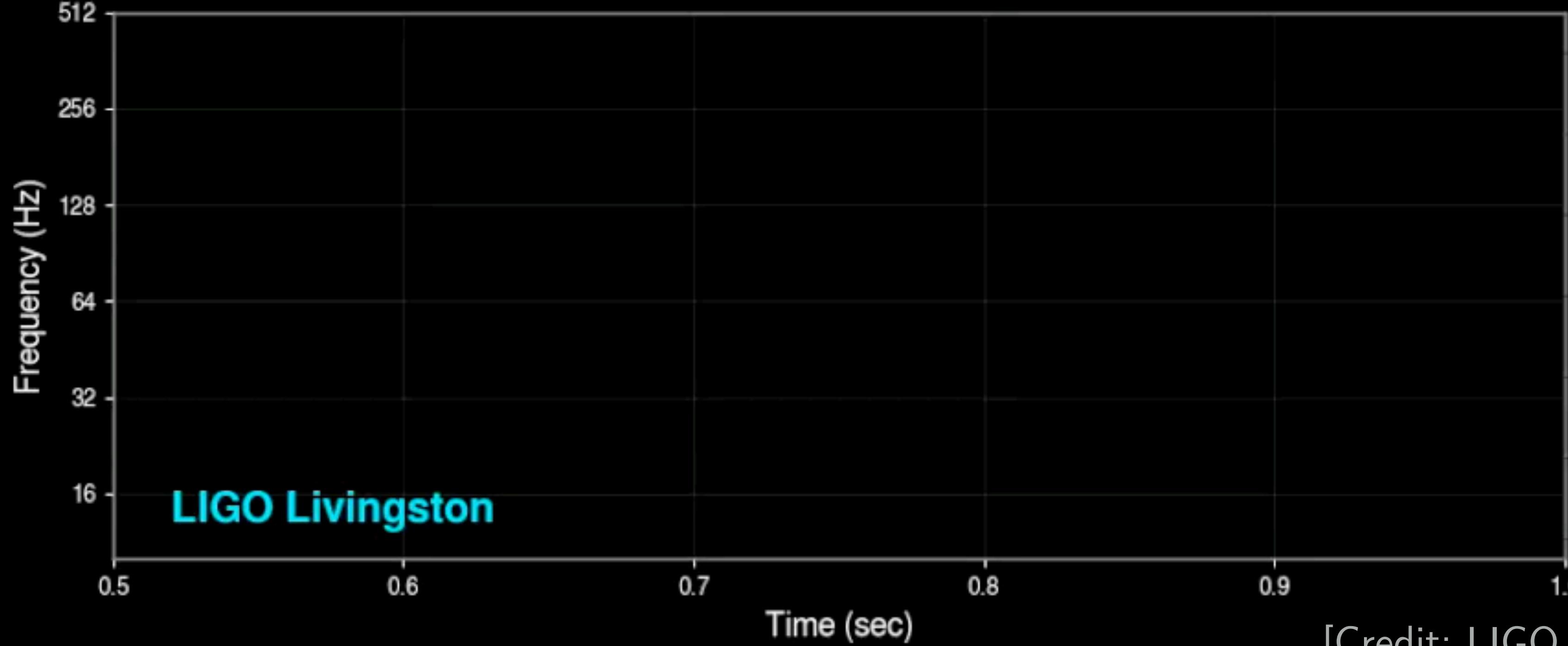
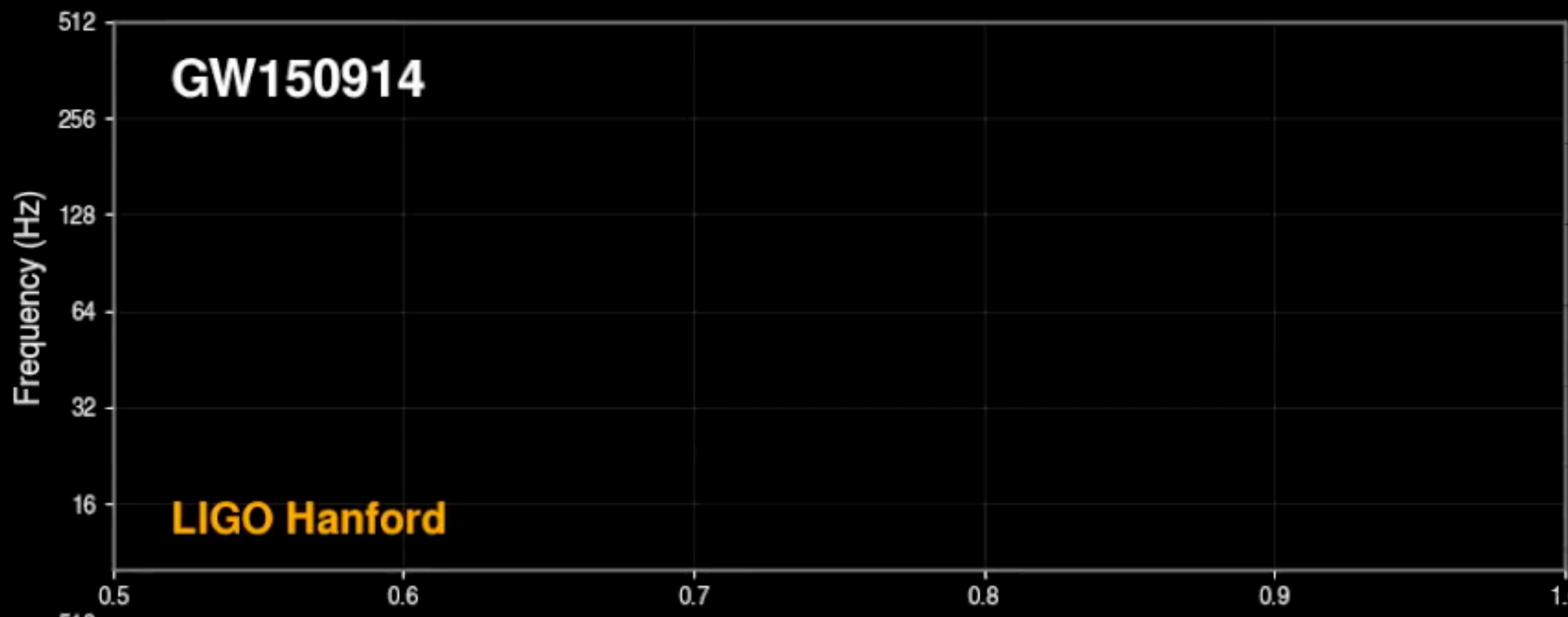
— cWB Reconstruction

GW231123: puzzling properties (high masses & spins!)

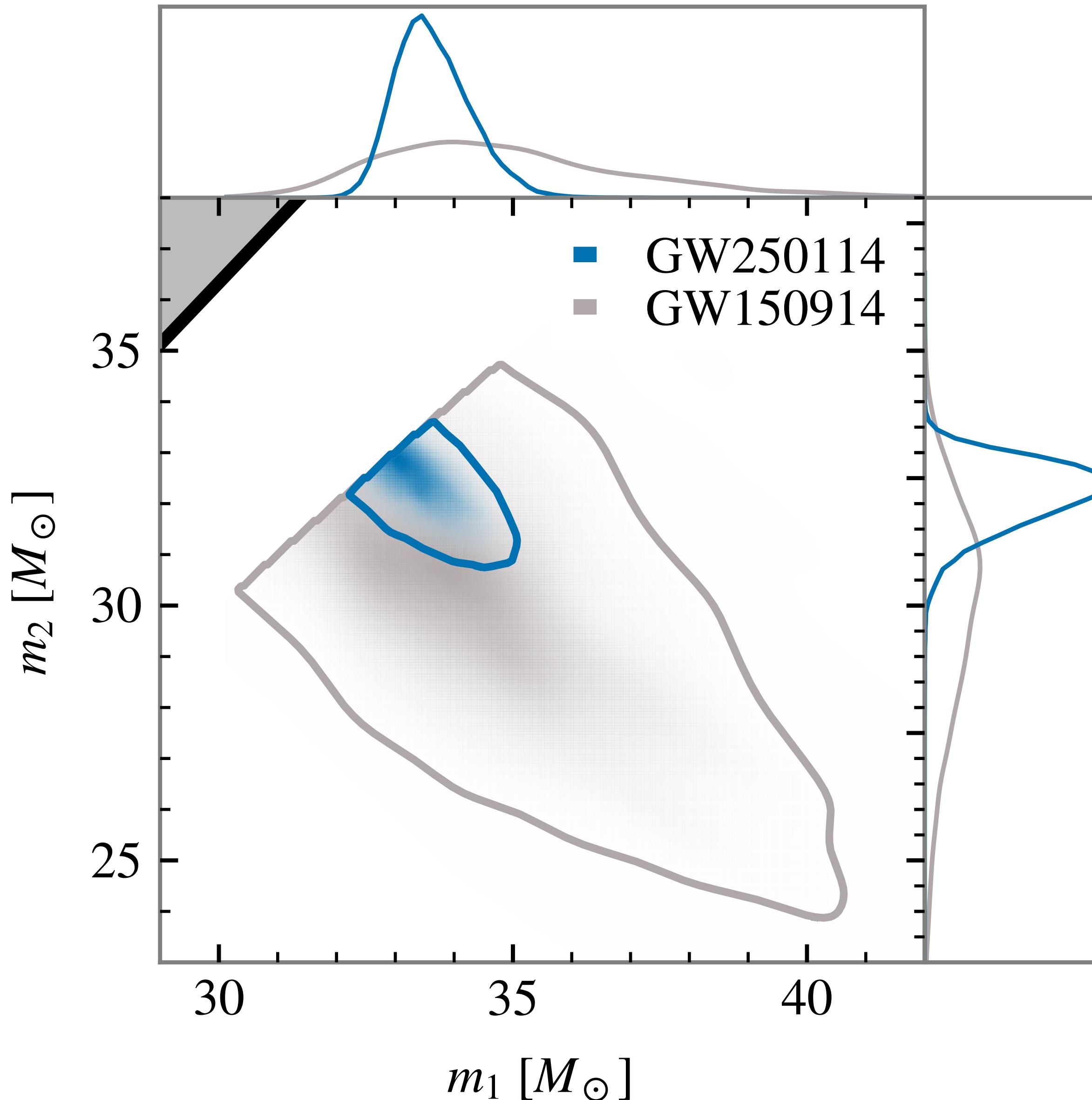


GW250114: the loudest event ever detected (*signal-to-noise* of 80!)

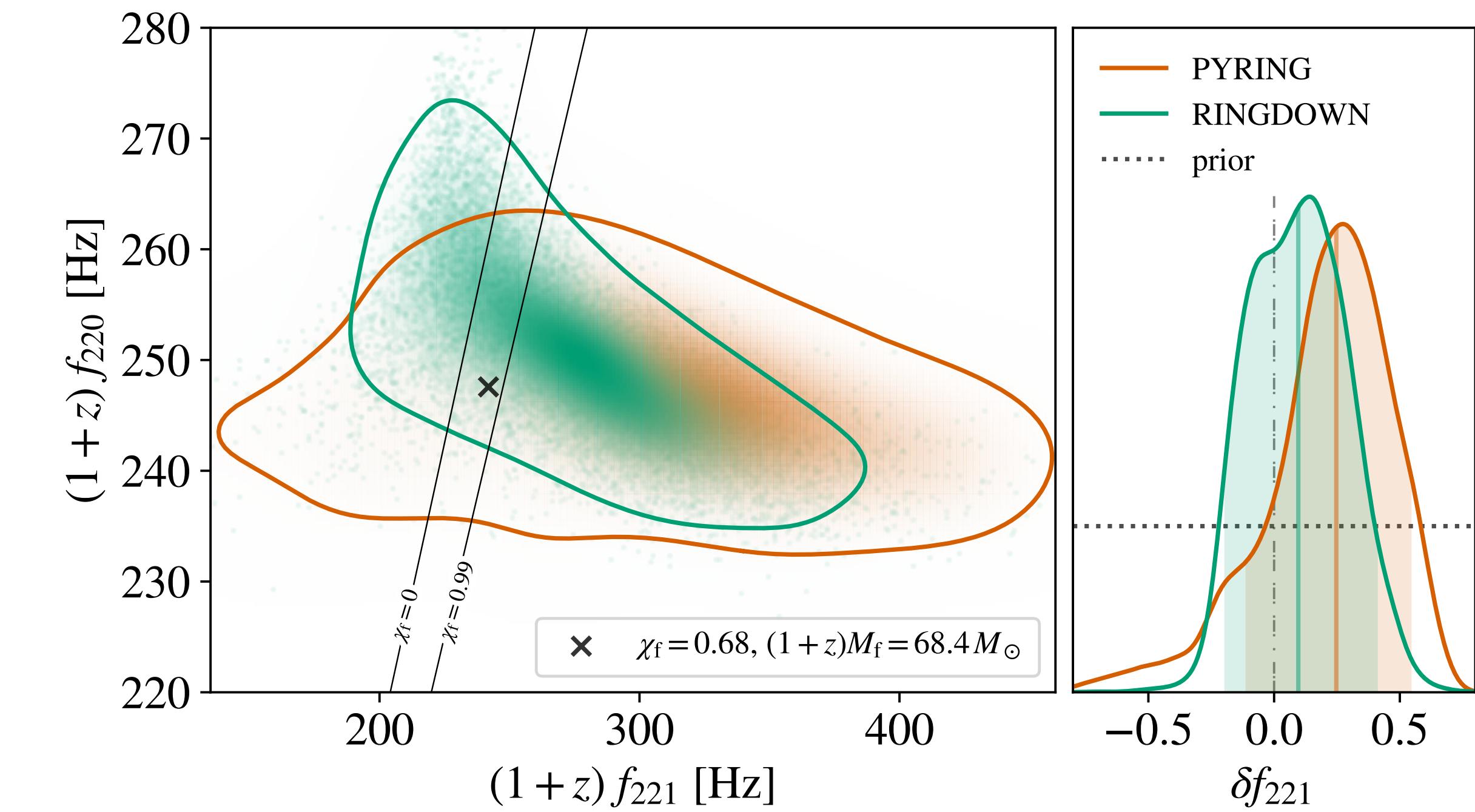




GW250114: precision measurements, even in the ring-down!



Hawking area law at 4.4σ !



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](#))
- GW230814: single detector, SNR 40, test gravity ([arXiv](#))
- GW250114: loudest ever, SNR 80! ([PRL](#)), black hole spectroscopy & test gravity ([arXiv](#))

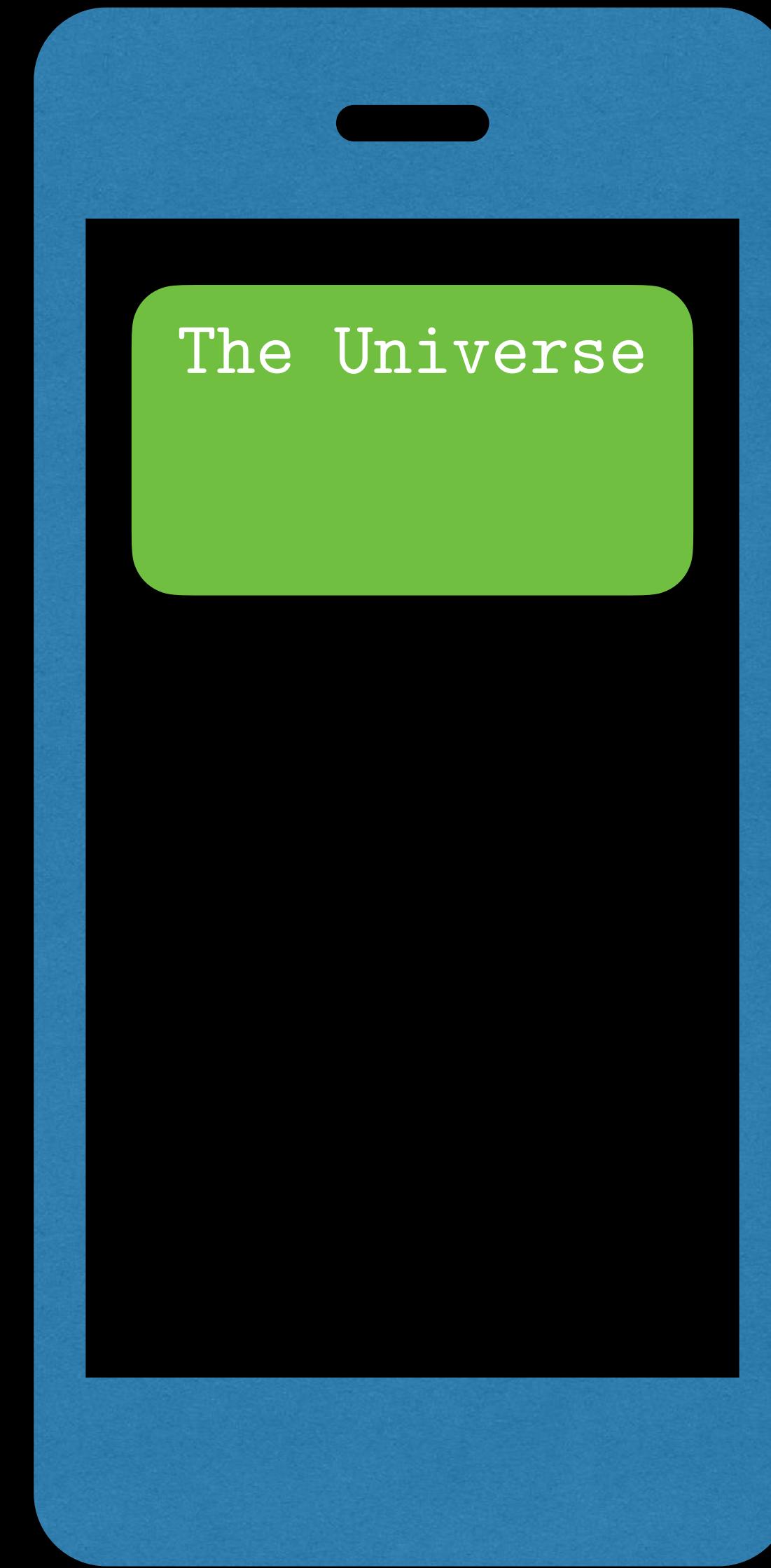
And more: upper limits on stochastic backgrounds ([arXiv](#)), searches for continuous sources...

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

<https://gracedb.ligo.org/superevents/public/04/#>

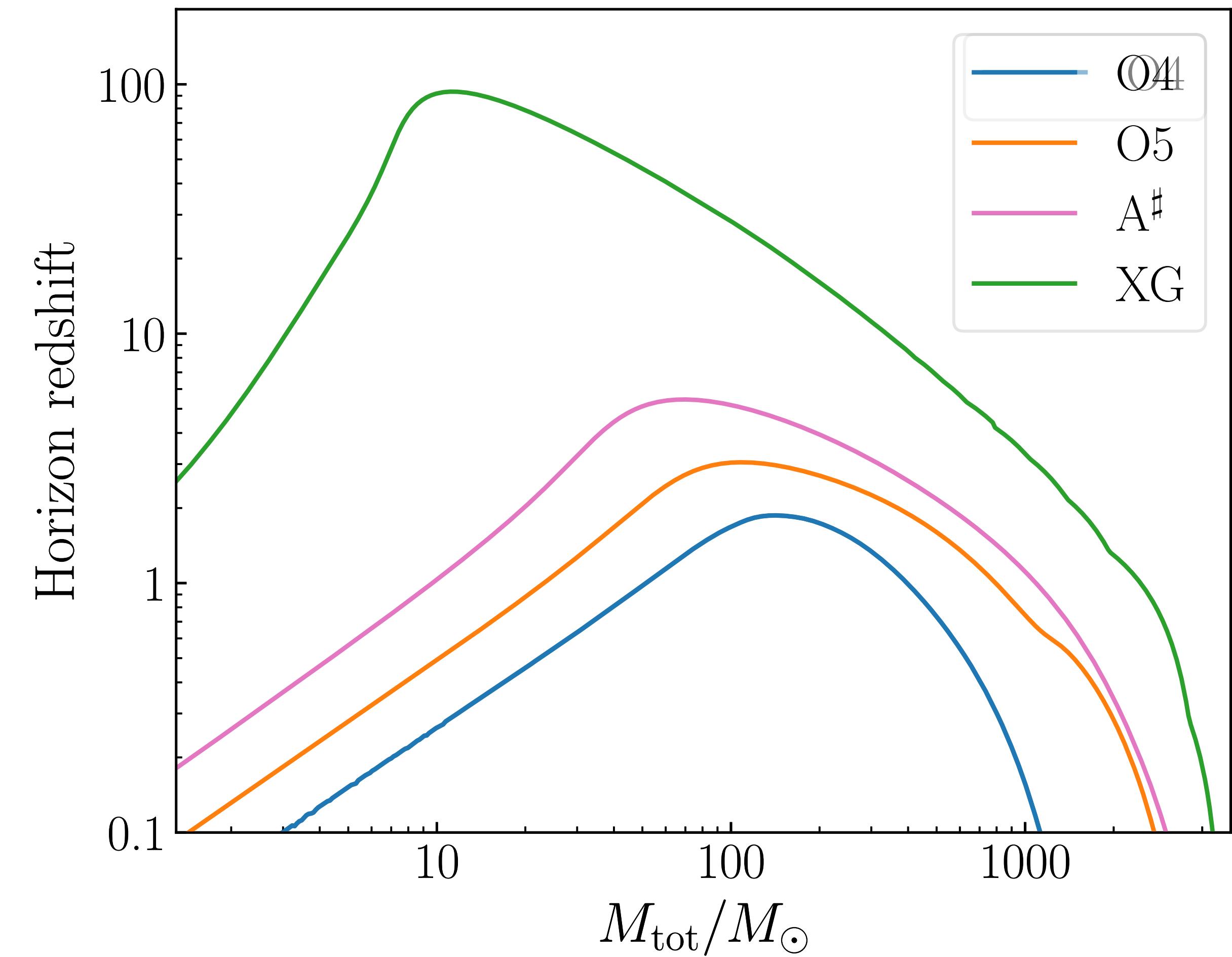
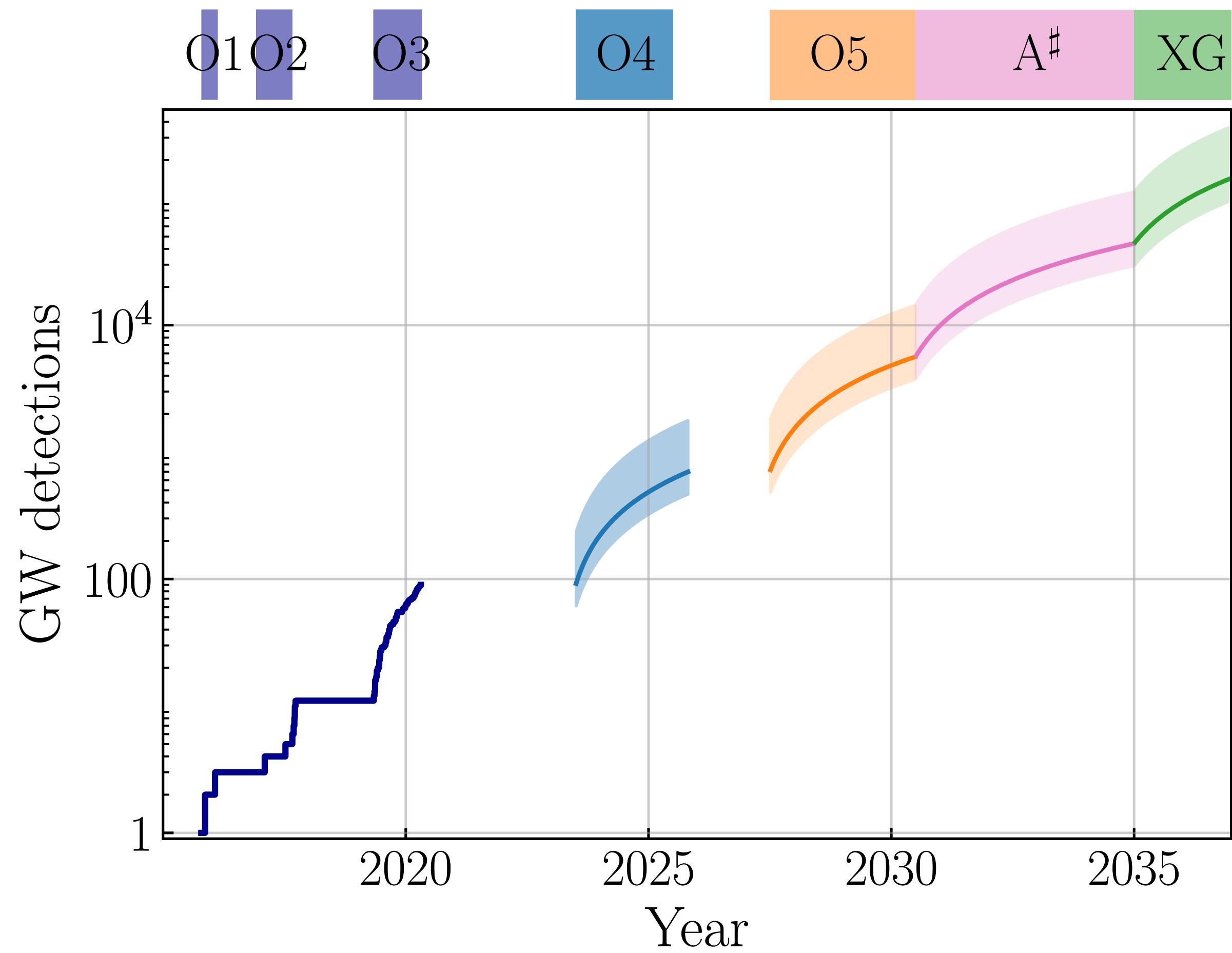


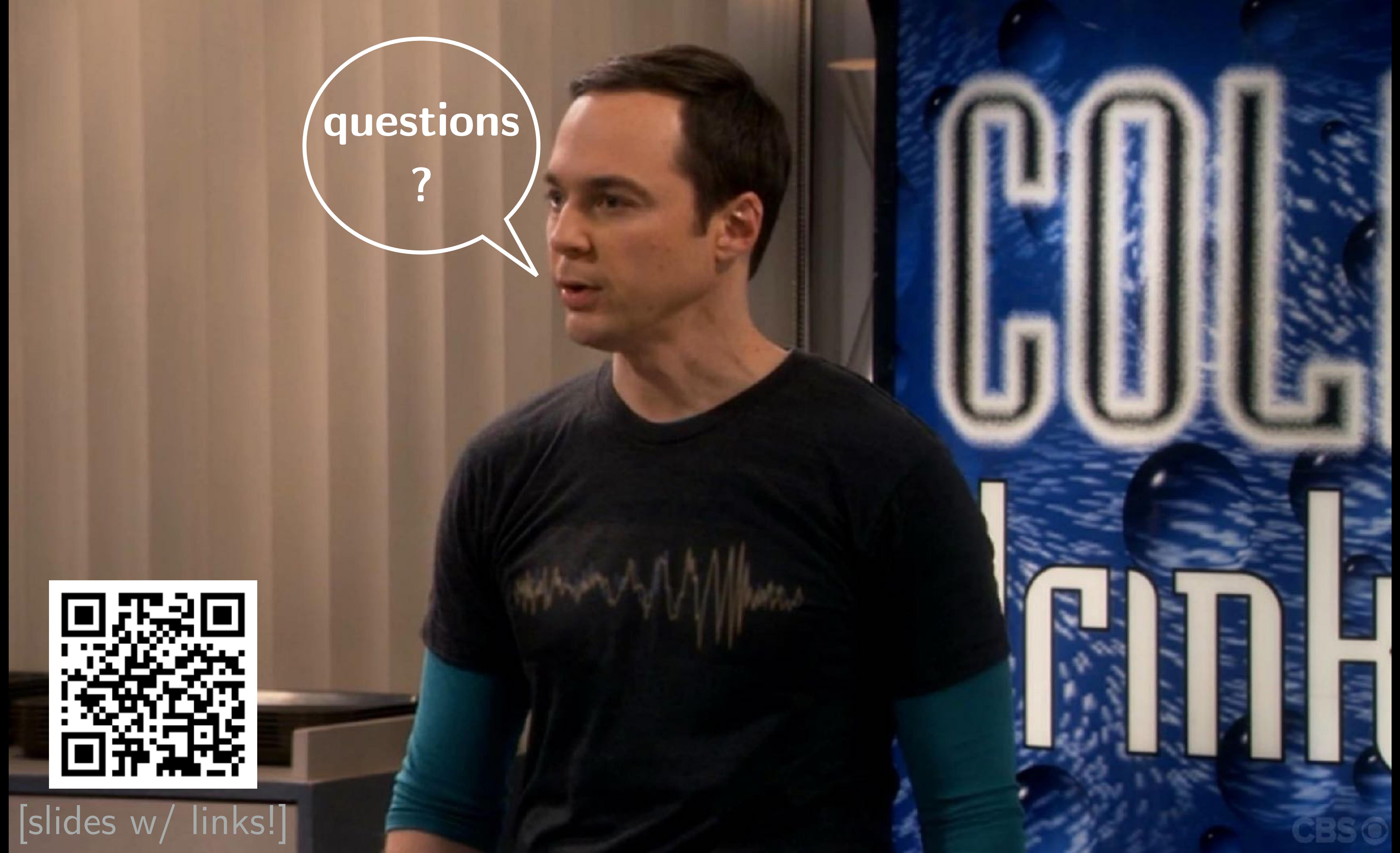
Check arXiv
for more
papers soon!



[get alerts for
new candidates]

The future: big data & distant Universe!



A photograph of Sheldon Cooper from the TV show "The Big Bang Theory". He is wearing a black t-shirt with a faint, abstract graphic on it. A white speech bubble with a black outline is positioned above his head, containing the word "questions" in white capital letters. Below the question mark is a single black question mark. To the left of Sheldon, there is a white QR code. To the right, a large blue banner with white text reads "COOL GUY" and "GEEK".

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