LIGO & Future GW Detectors

Patrick Brady
LIGO Scientific Collaboration

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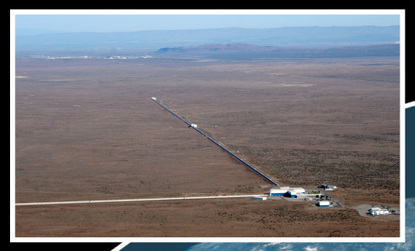
International Gravitational-Wave Observatory Network (I-G-W-N)



LIGO Hanford

LIGO Livingston

GEO600

Virgo

KAGRA

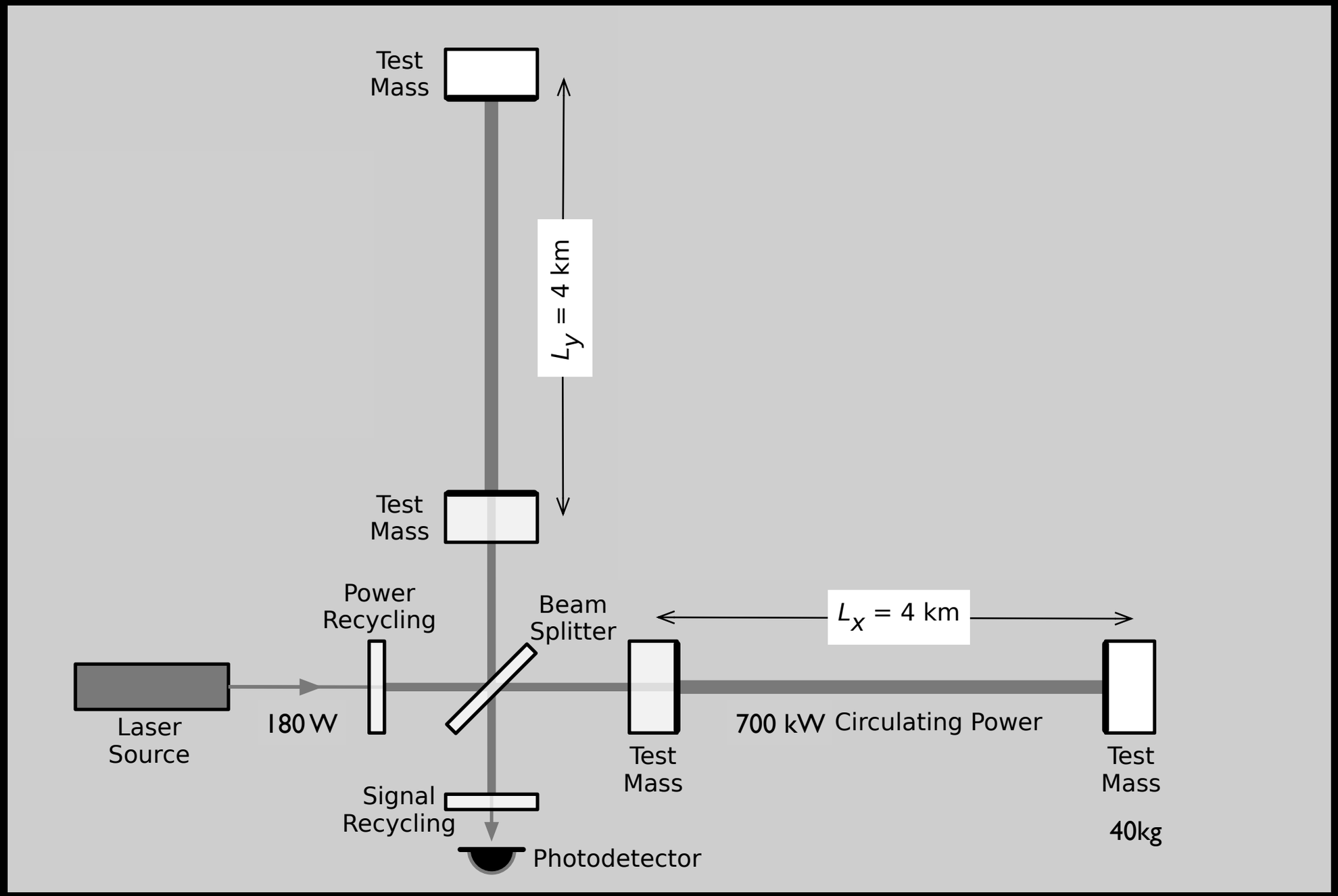
LIGO India

Gravitational Wave Observatories

Credit: LIGO

LIGO

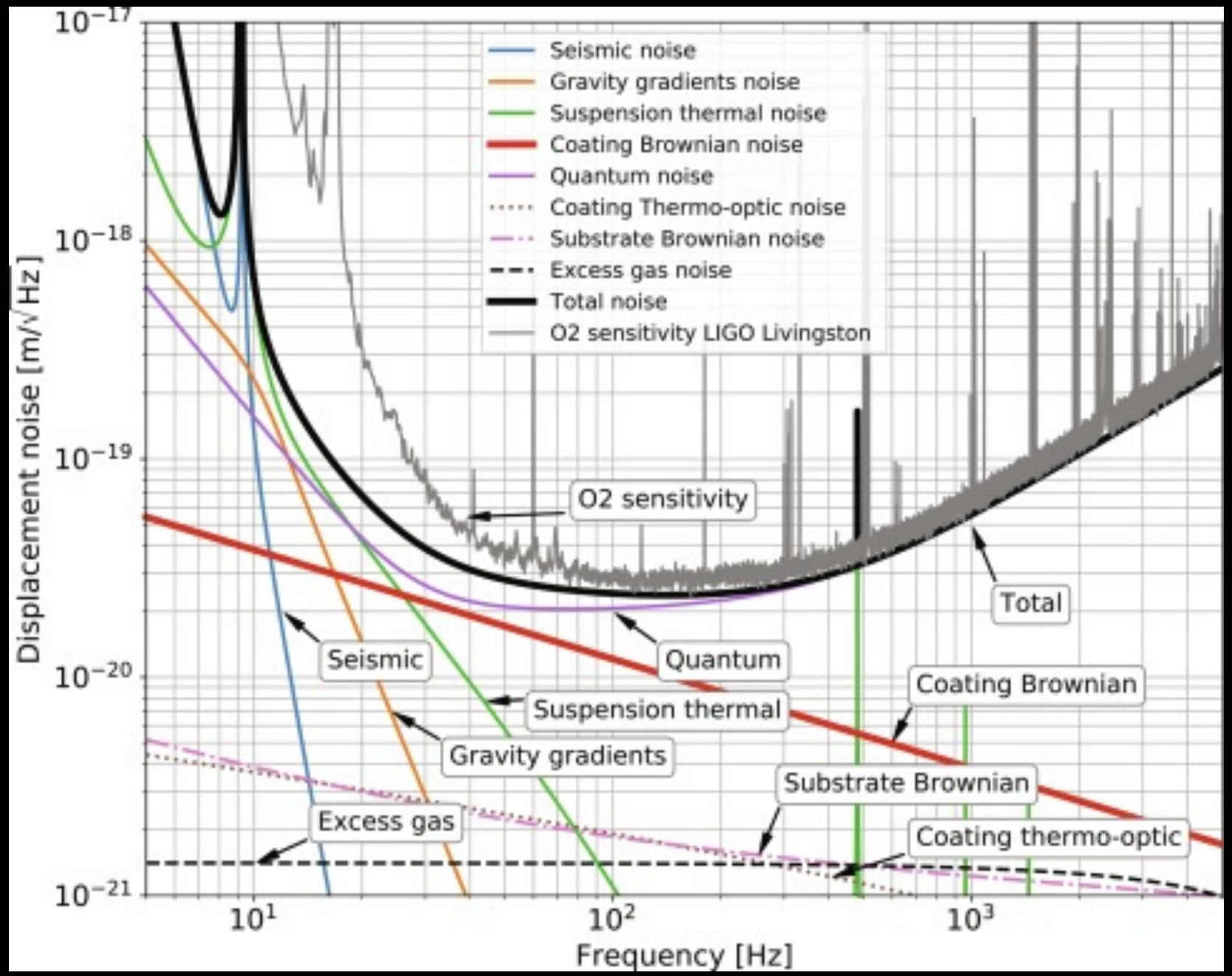
Schematic detector



LIGO

Noise budget

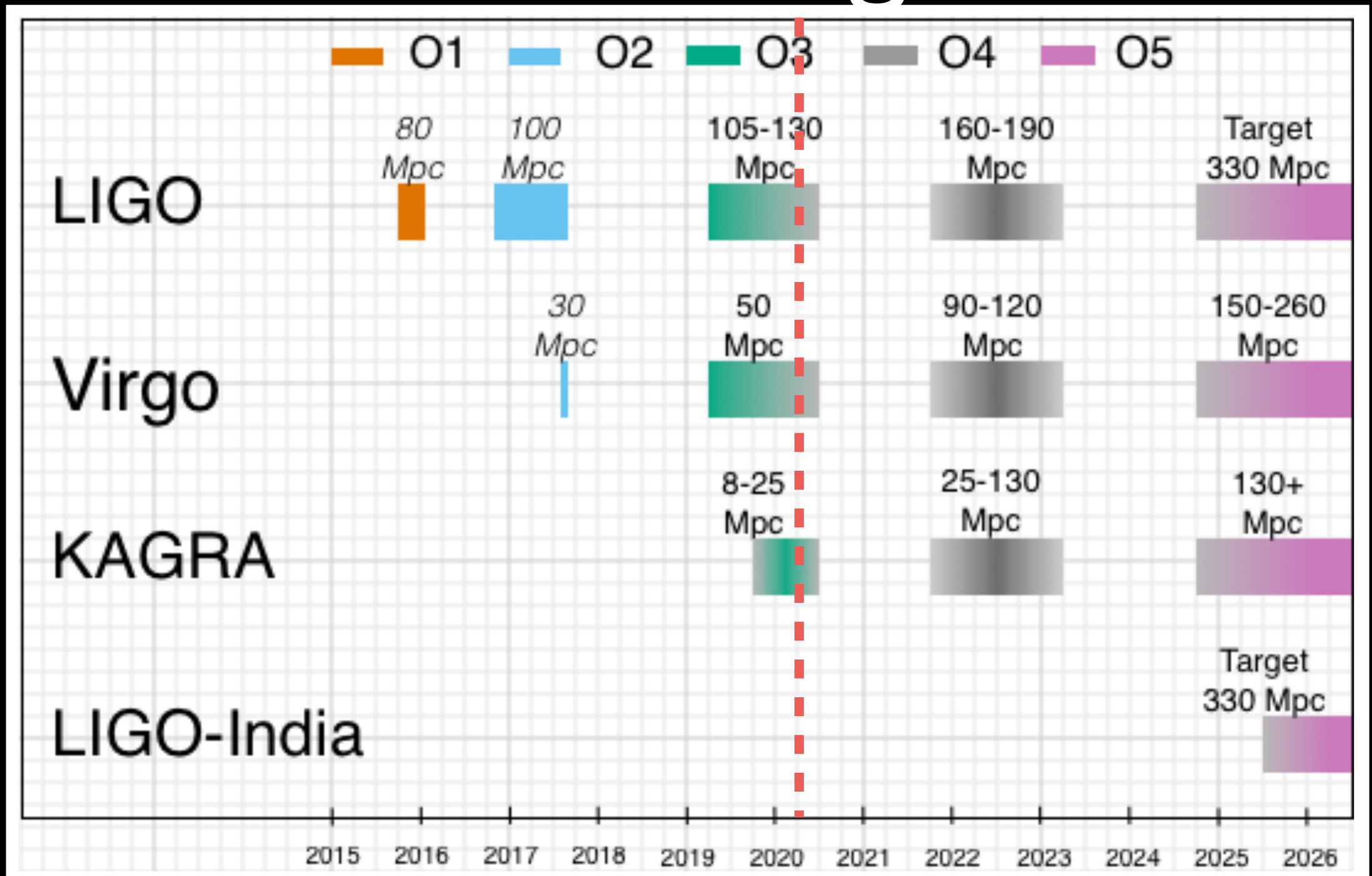
$\sqrt{S_n(|f|)} \times$ arm length



Precision interferometry for gravitational wave detection: Current status and future trends
Vajente, Gustafson, Reitze in Advances In Atomic, Molecular, and Optical Physics, Academic Press, 68, 2019

LIGO

Observing runs



LIGO-Virgo-KAGRA Collaborations, Prospects for Localizing Gravitational-wave Transients … , arXiv:1304.0670

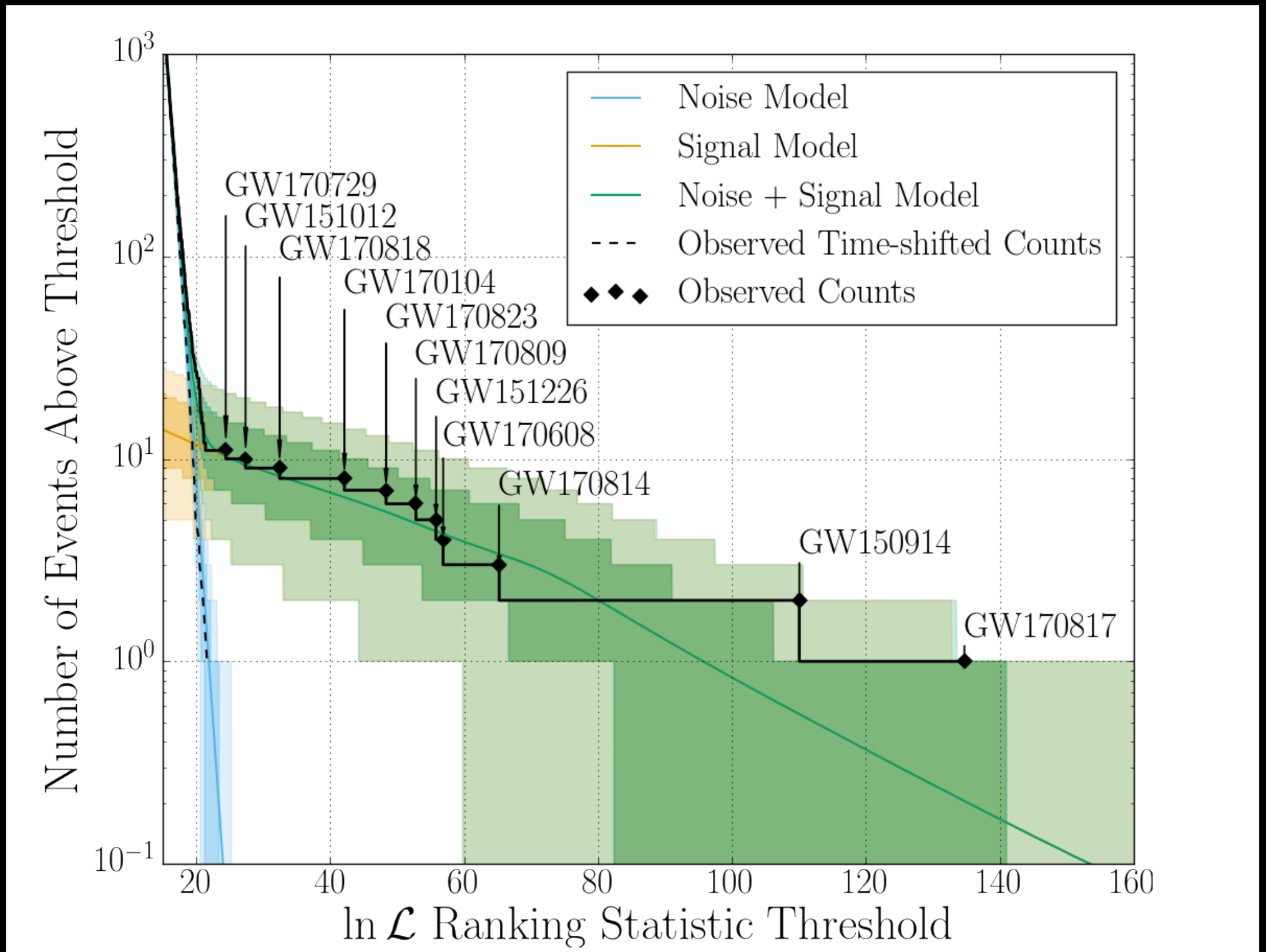
LIGO

GWTC-1

- First LIGO-Virgo Gravitational-wave Transient Catalog (GWTC-1) released in December 2018
- 11 events with false-alarm-rate < 1/30 days and > 50% chance of being astrophysical
  - 10 binary black hole (BBH) mergers
  - 1 binary neutron star (BNS) merger
- 14 marginal candidates < 50% chance of being astrophysical

Abbott et al., GWTC-1:A Gravitational-Wave Transient Catalog…

LIGO Gravitational-wave Transient Catalog



Abbott et al.,
GWTC-1:A Gravitational-Wave Transient Catalog...

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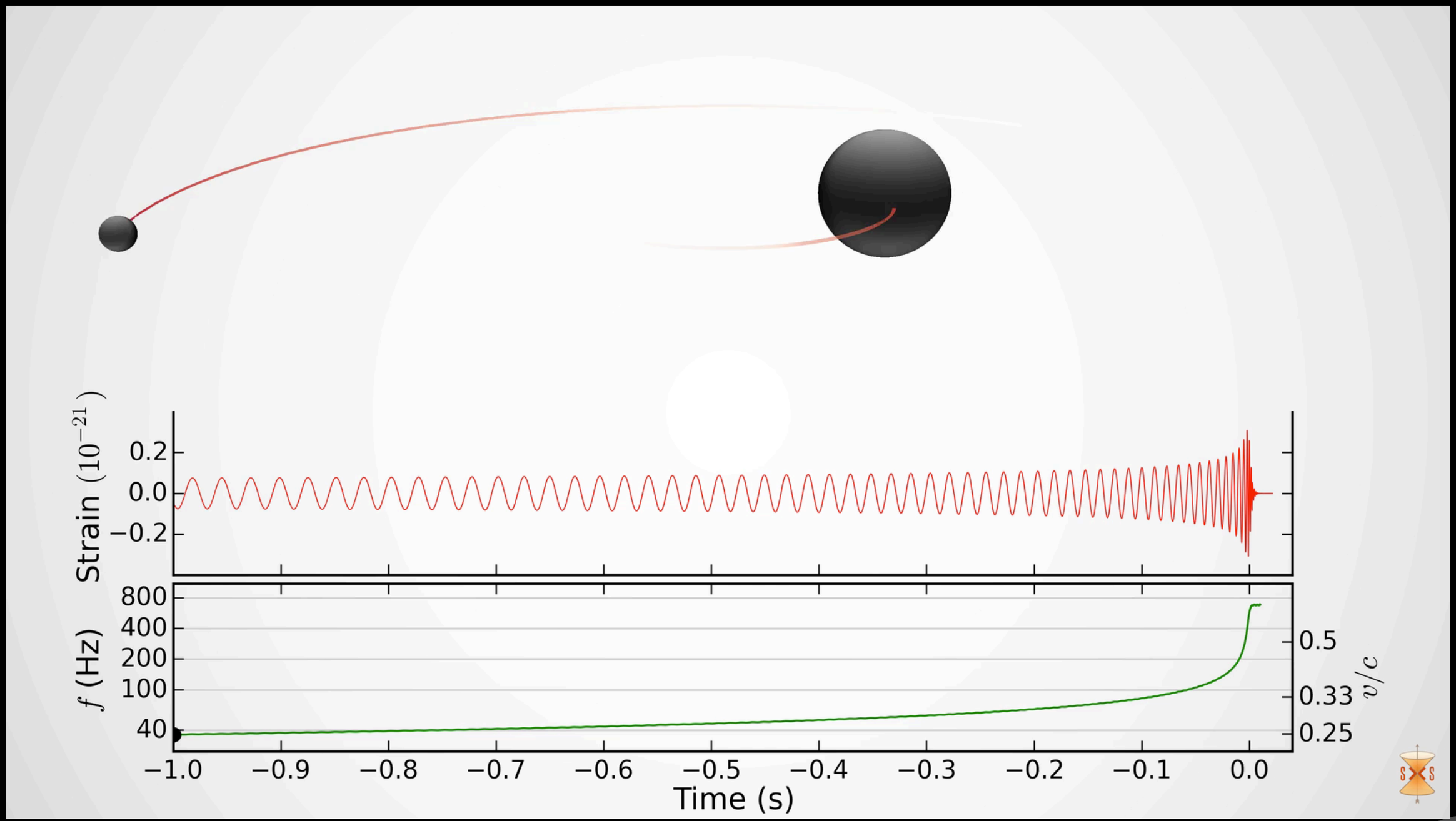
Binary systems

Credit: SXS Collaboration



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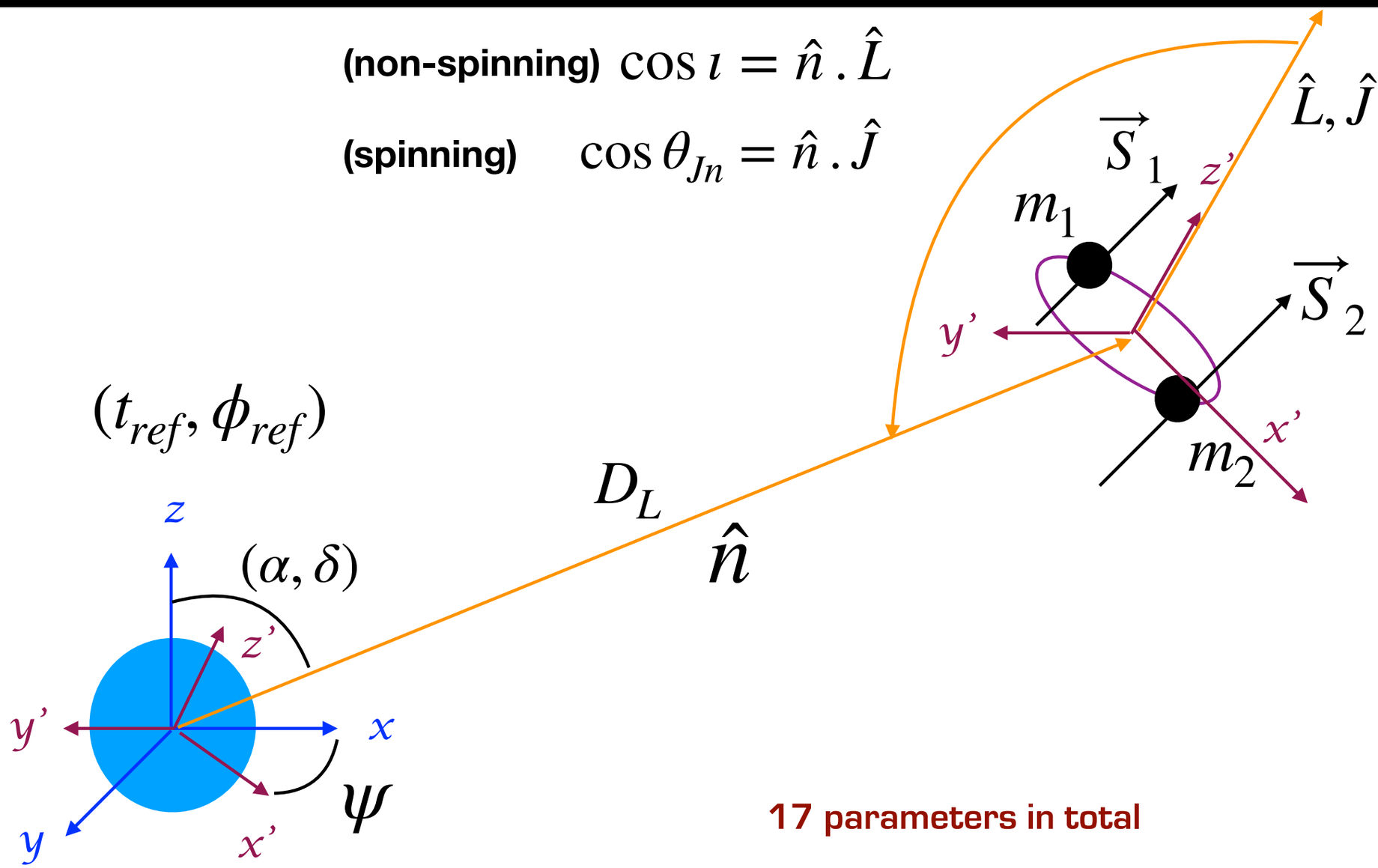
Strain at detector

$$h(t - t_c; \alpha, \delta, \psi, \overrightarrow{\lambda}) = F_+(\alpha, \delta, \psi) h_+(t - t_c; \overrightarrow{\lambda}) + F_\times(\alpha, \delta, \psi) h_\times(t - t_c; \overrightarrow{\lambda})$$

(non-spinning) $\cos \iota = \hat{n} \,.\, \hat{L}$

(spinning) $\cos \theta_{Jn} = \hat{n} \,.\, \hat{J}$



17 parameters in total

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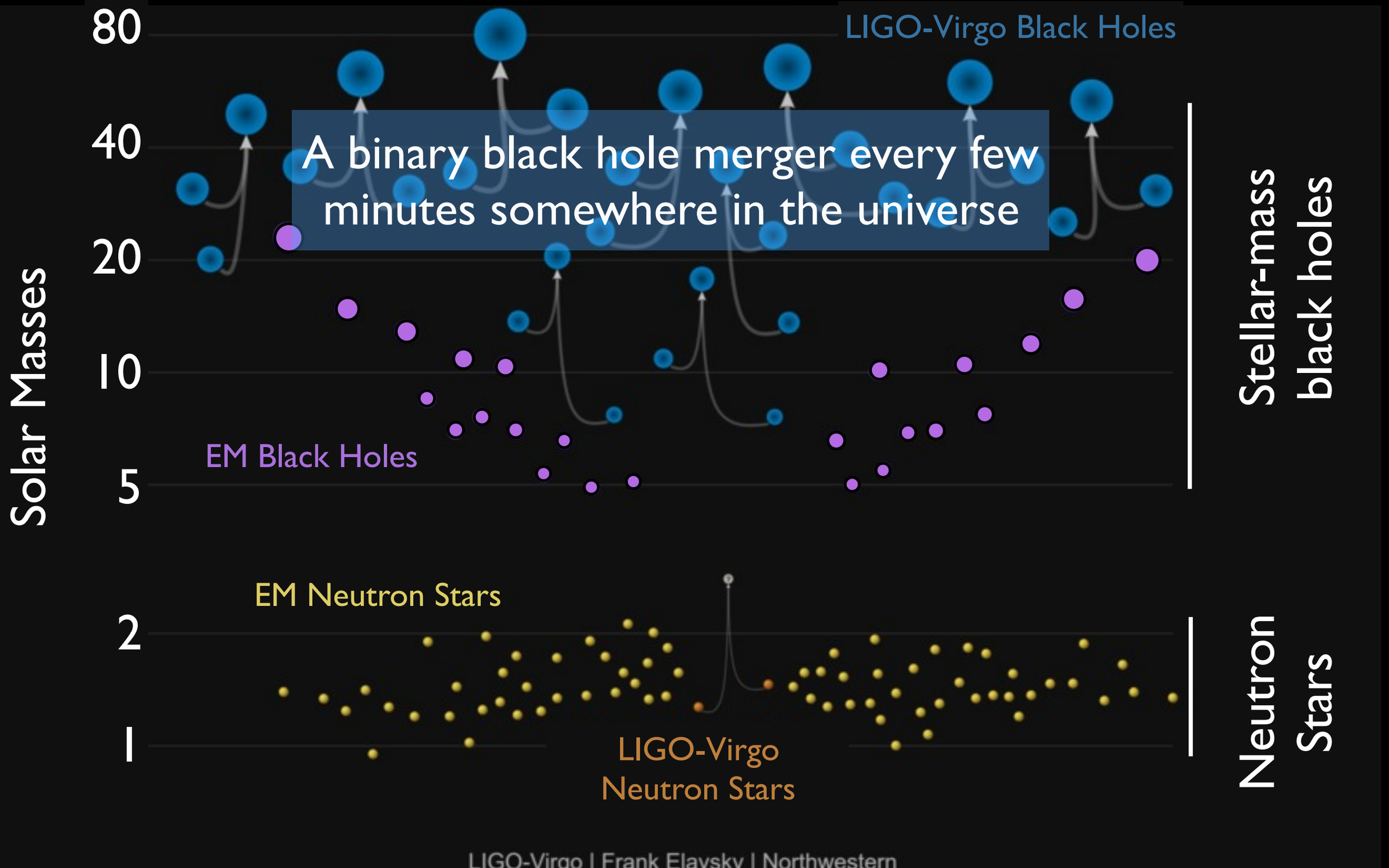
GWTC-1 with EM



Open Data

- O1 strain data released in 2018; O2 strain data released in 2019
  - https://www.gw-openscience.org
- Six additional candidate BBH in O2 reported by IAS group

Name	$\mathrm{FAR}^{-1}(\mathrm{O2})^{\mathrm{b}}$	$\frac{W(\mathrm{event})}{\mathcal{R}(\mathrm{event}\|\mathcal{N})}$ (O2)	p_{astro}
GW170121	2.8×10^3	> 30	> 0.99
GW170304	377	13.6	0.985
GW170727	370	11.8	0.98
GW170425	15	0.65	0.77
GW170202	6.3	0.25	0.68
GW170403	4.7	0.23	0.56

Venumadhav et al., New Binary Black Hole Mergers … , arXiv:1904.07214

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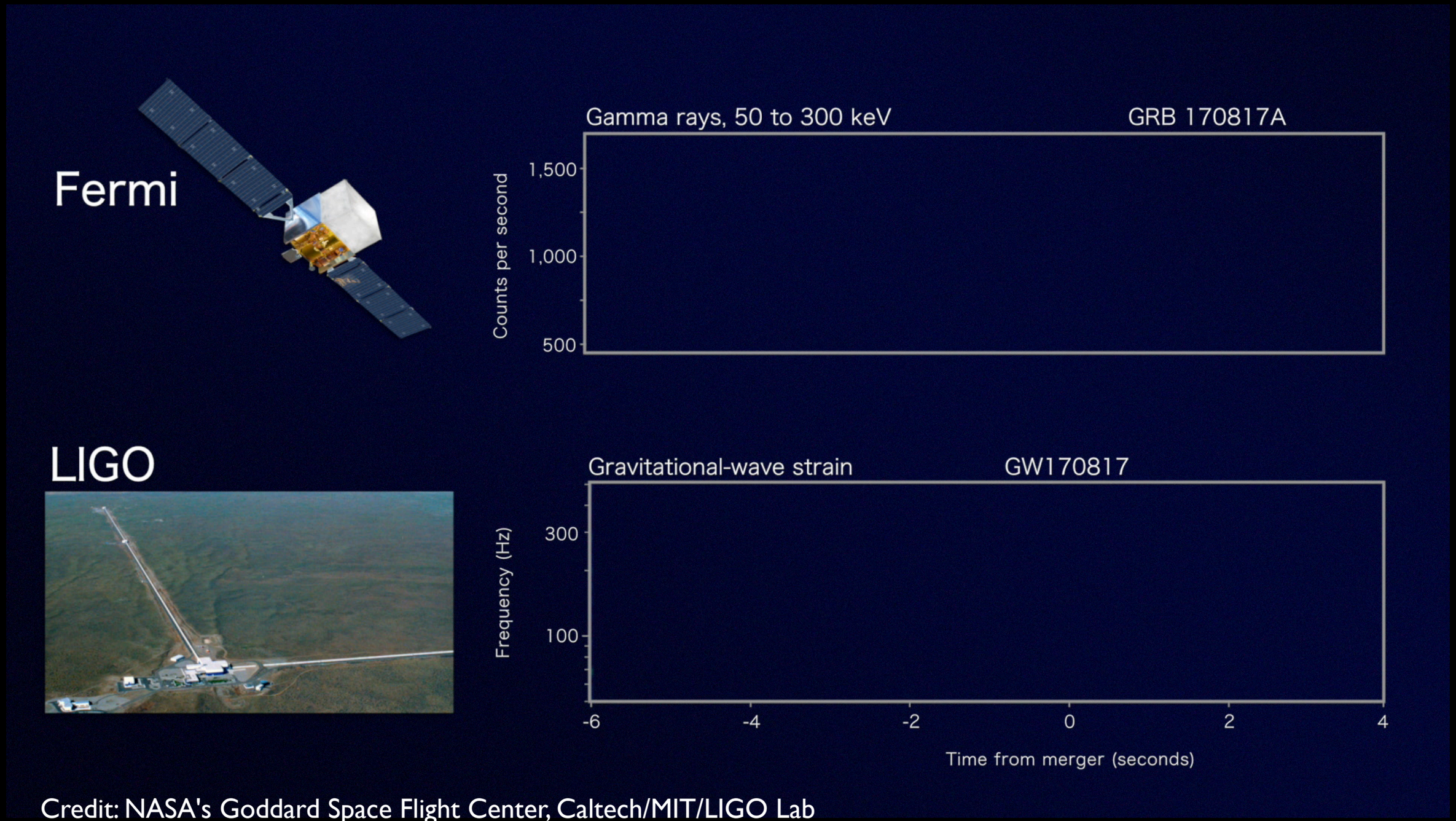
GW 170817



Credit: NASA's Goddard Space Flight Center, Caltech/MIT/LIGO Lab

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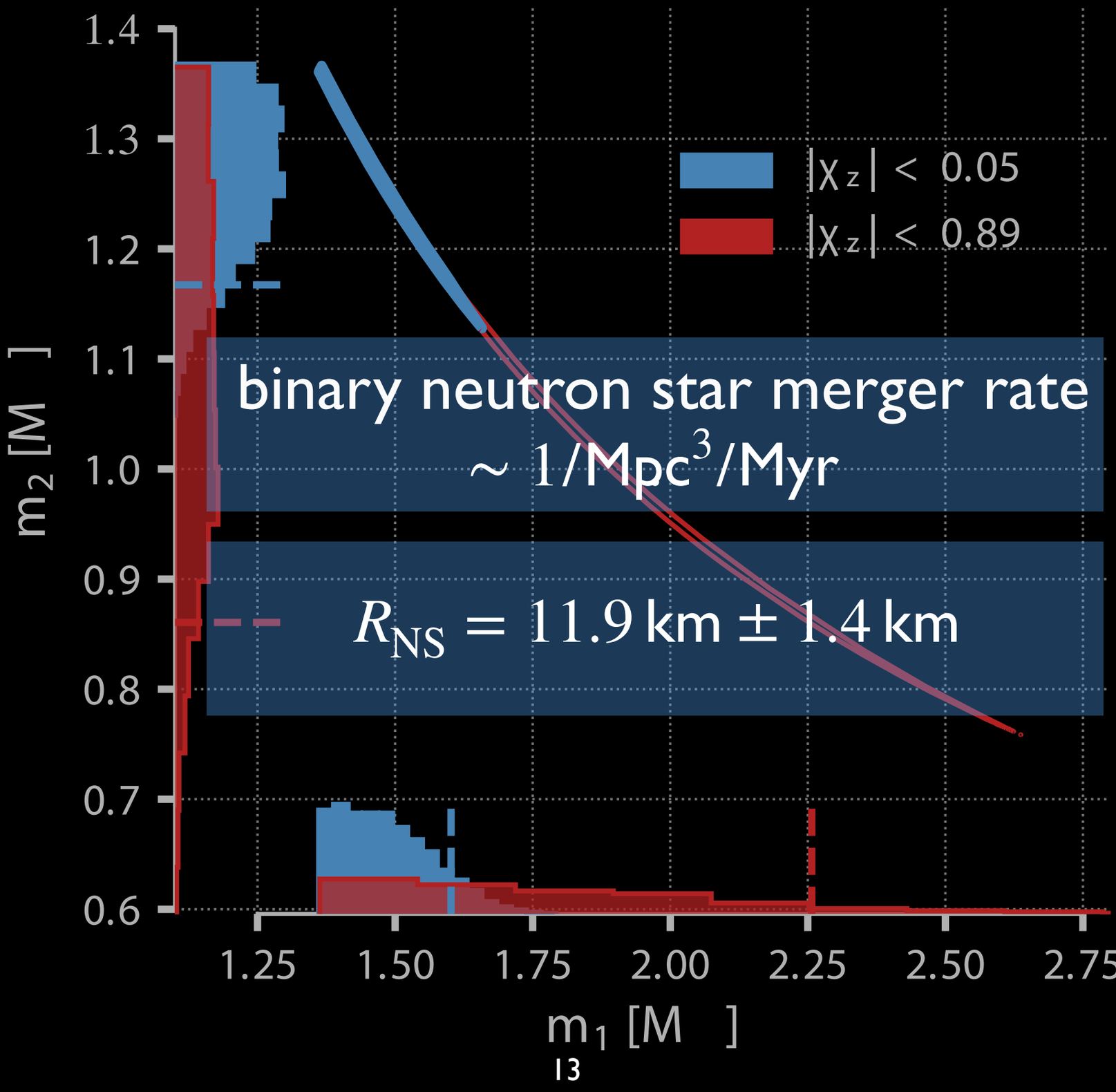
GW170817: Masses



Abbott et al, Phys. Rev. Lett. 119, 161101 (2017)

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Explosion

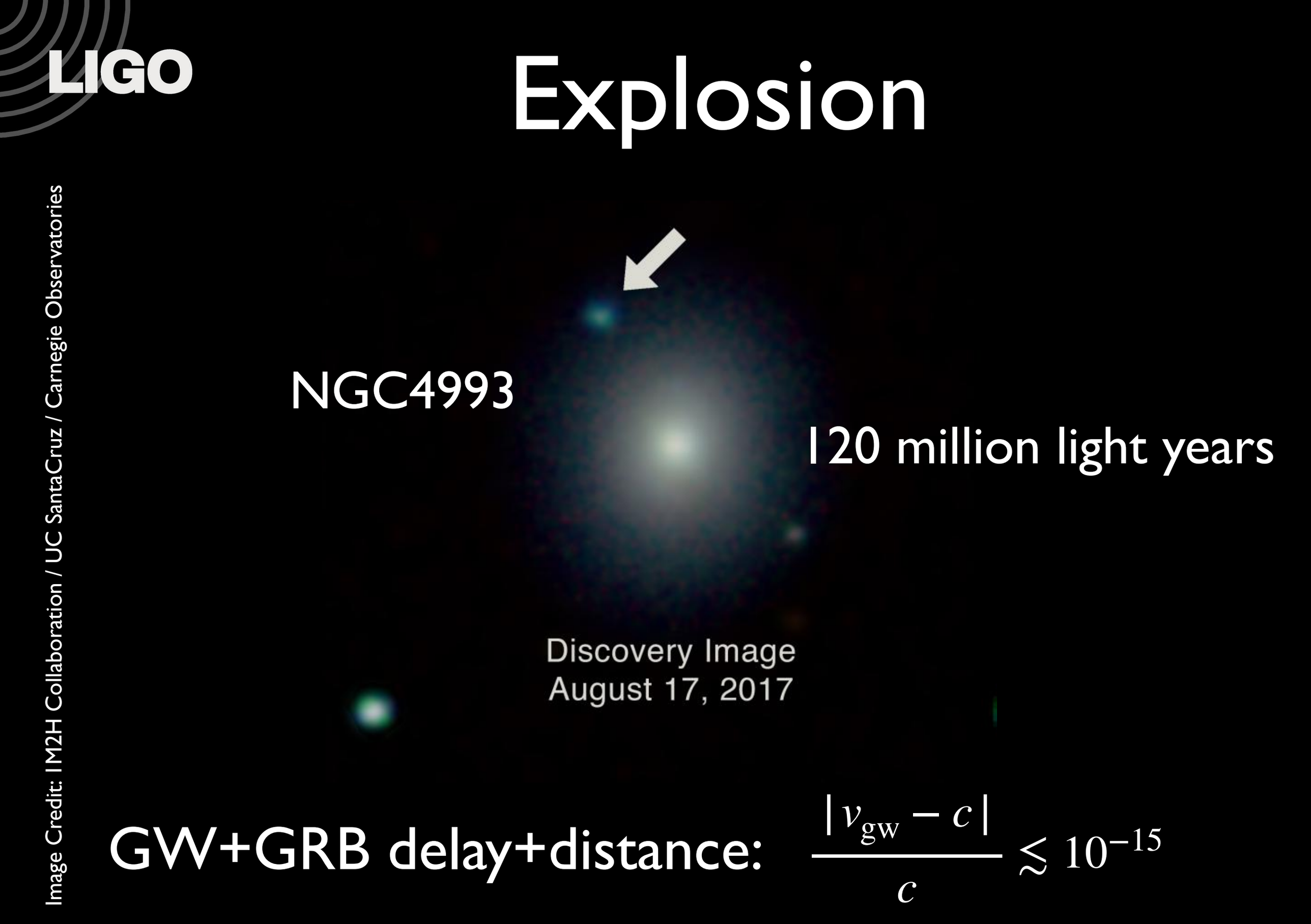

Image Credit: IM2H Collaboration / UC SantaCruz / Carnegie Observatories

GW+GRB delay+distance: $\frac{|v_{\rm gw} - c|}{c} \lesssim 10^{-15}$

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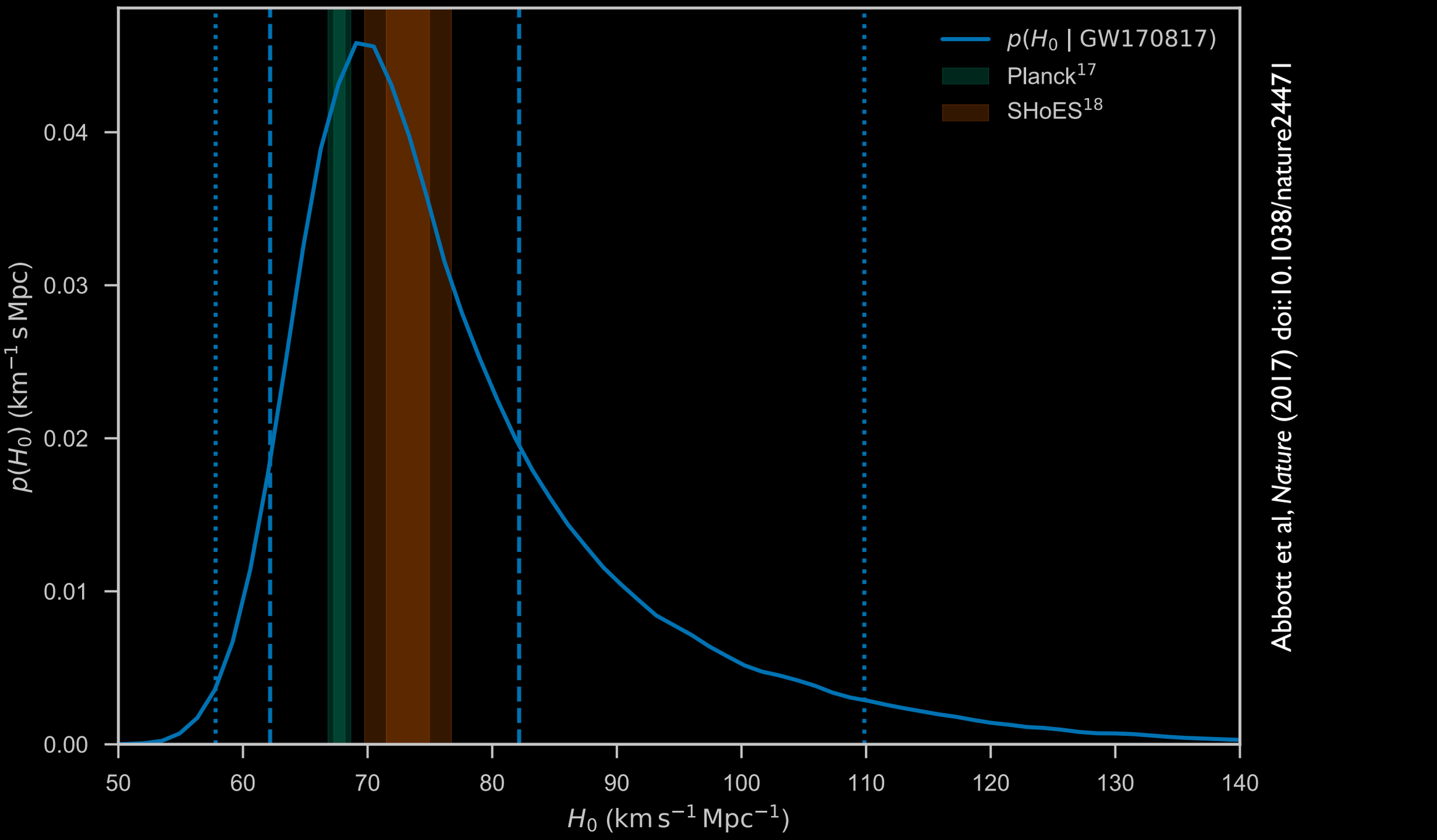
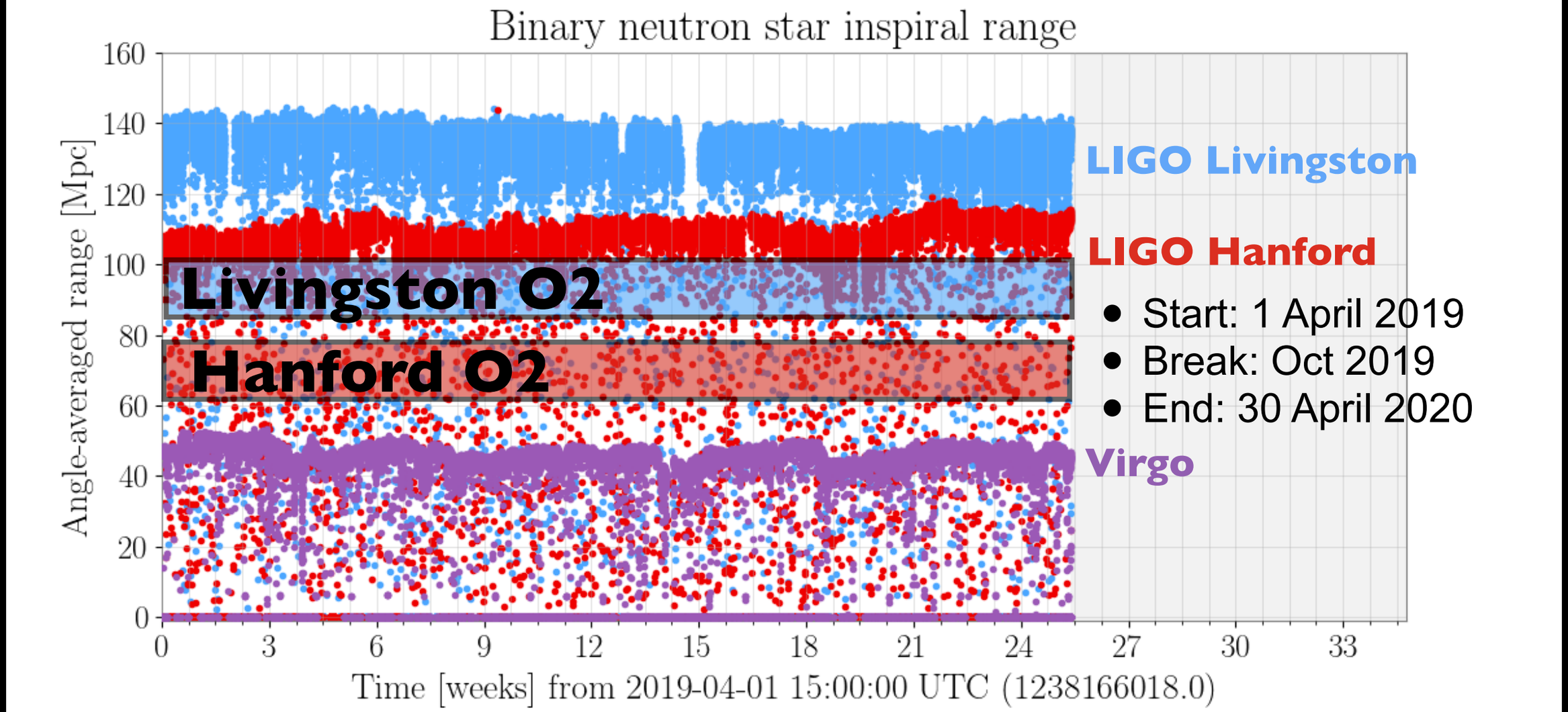
Expansion of Universe



Observing run O3



This is first 6 months (O3a).
Second 6 months (O3b) is similar.

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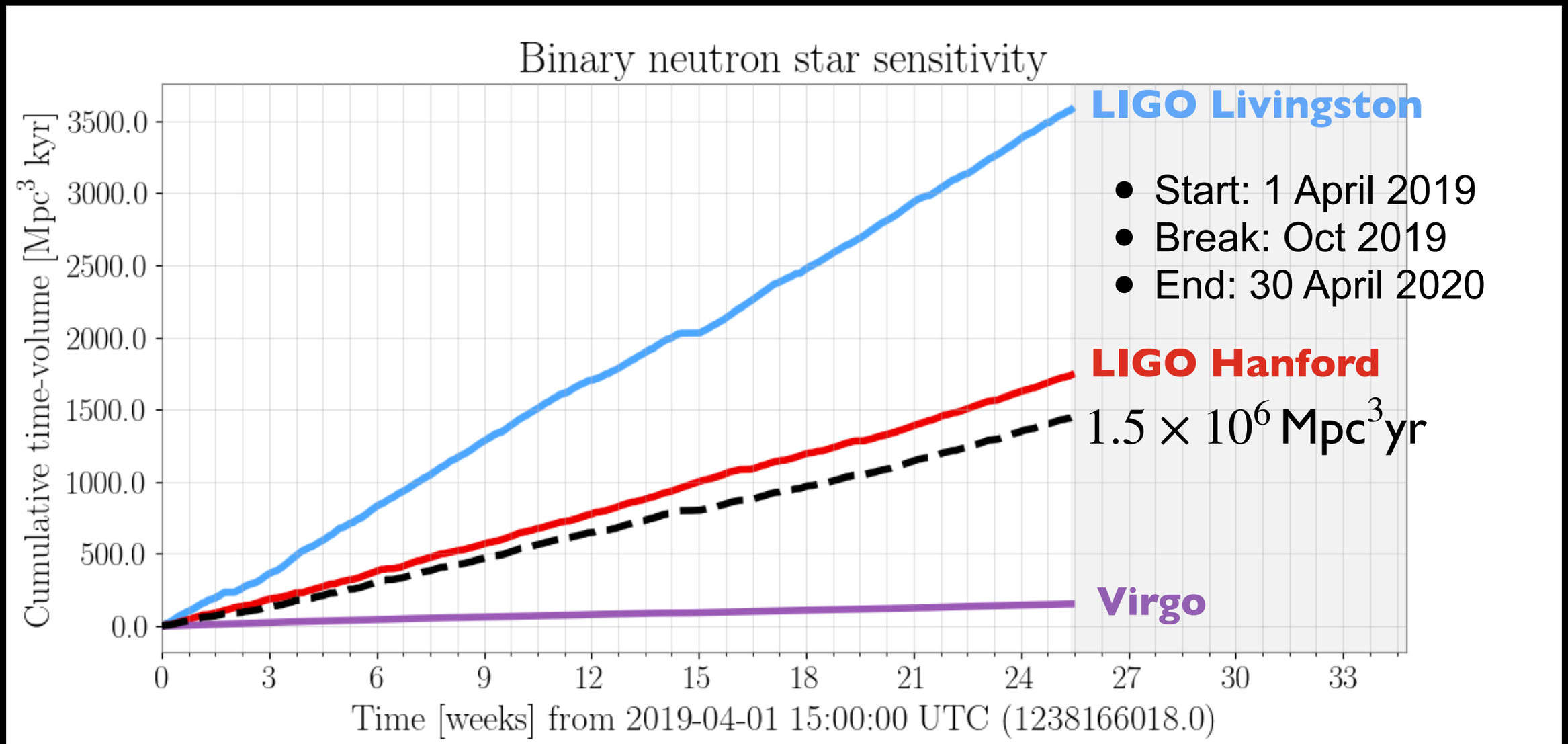
Observing run O3



This is first 6 months (O3a).
Second 6 months (O3b) is similar.

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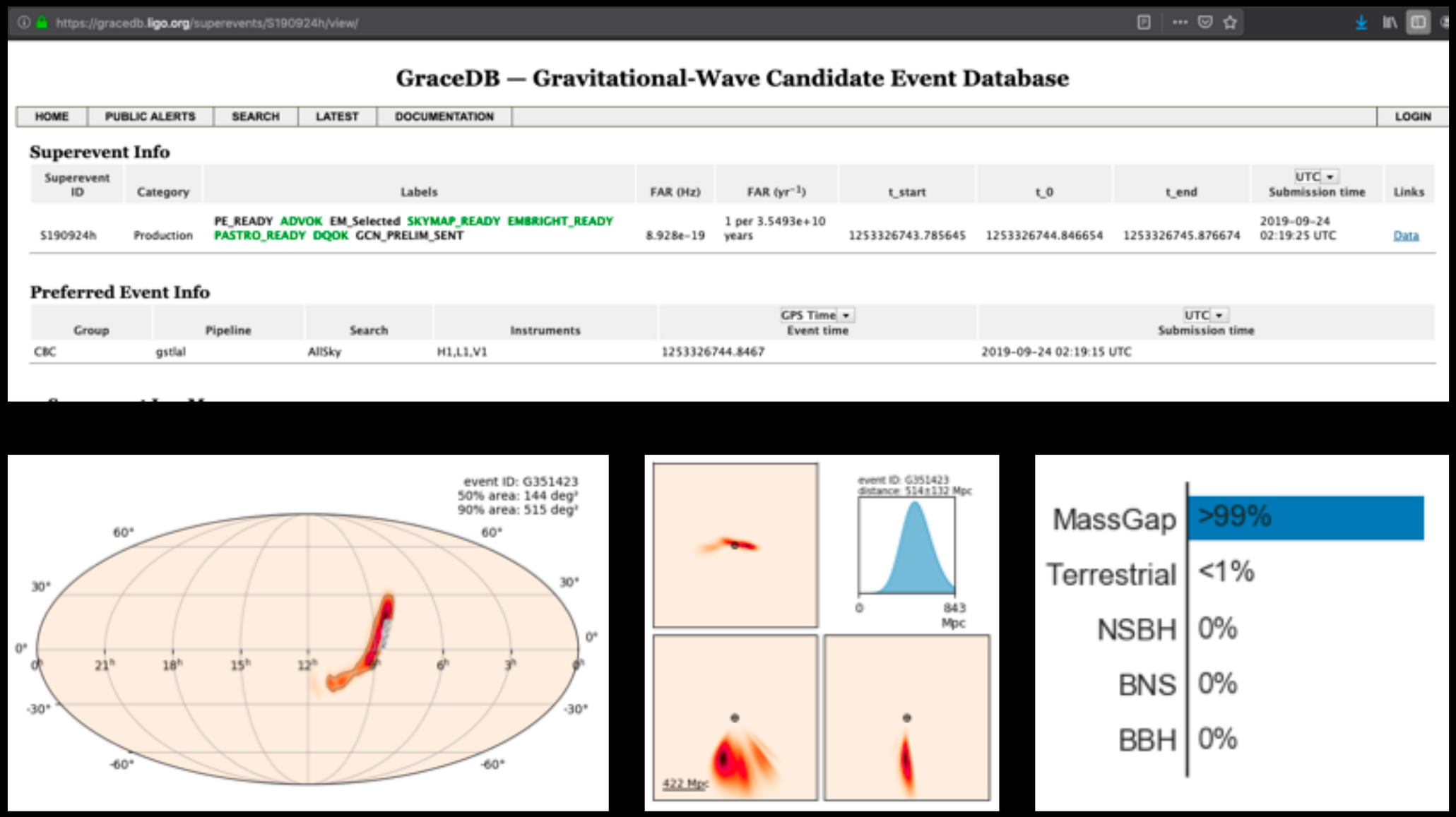
LIGO Low-latency Alerts in O3



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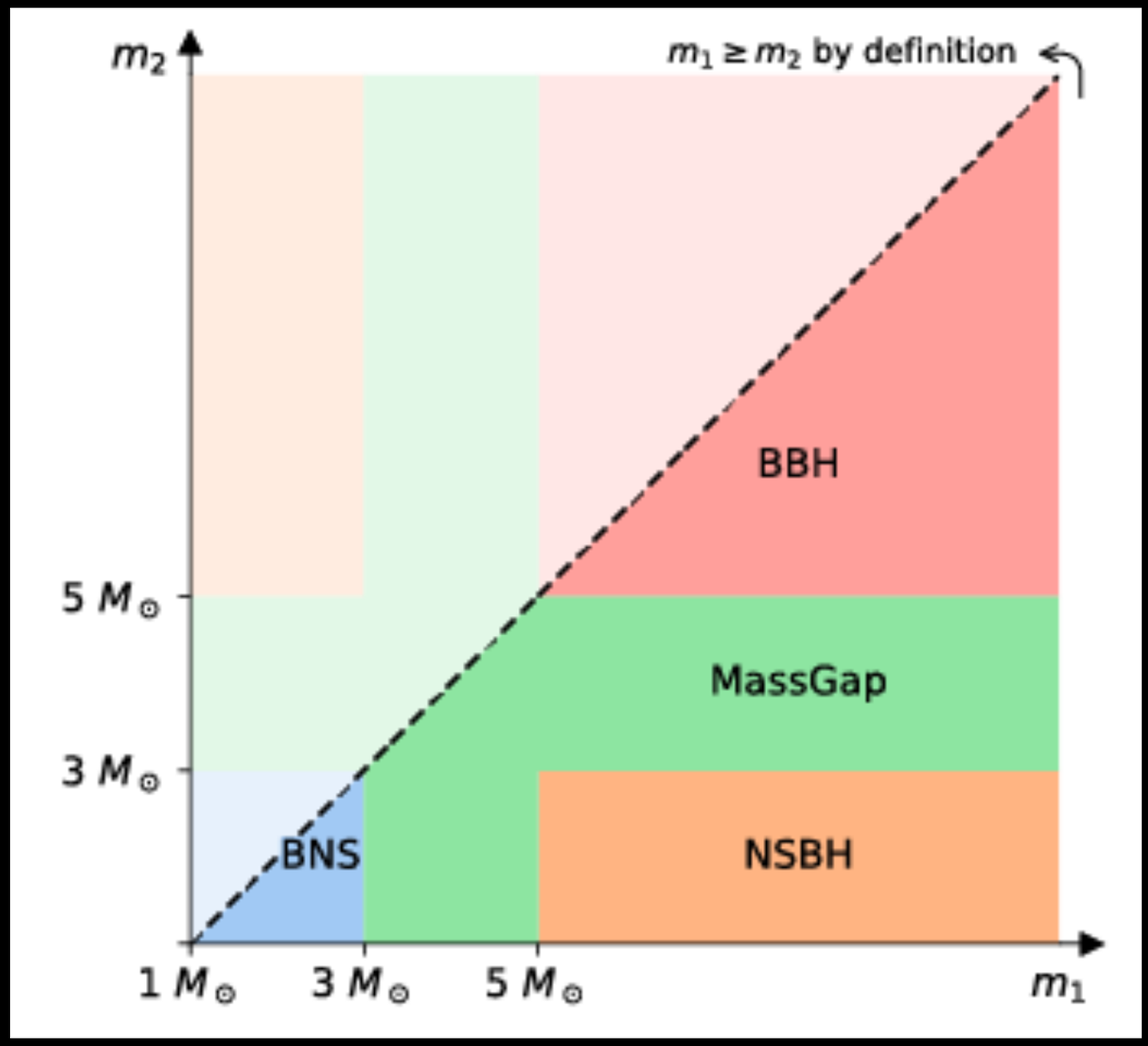
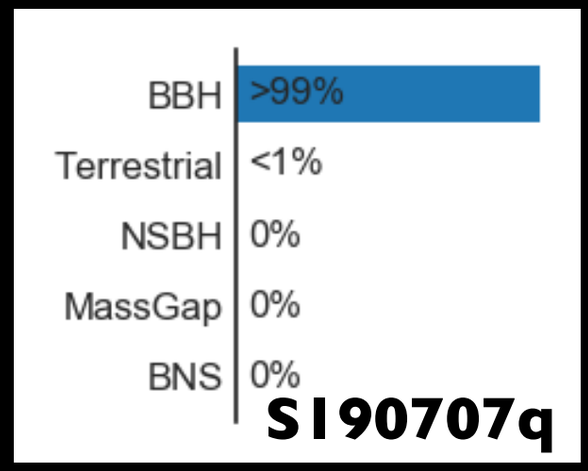
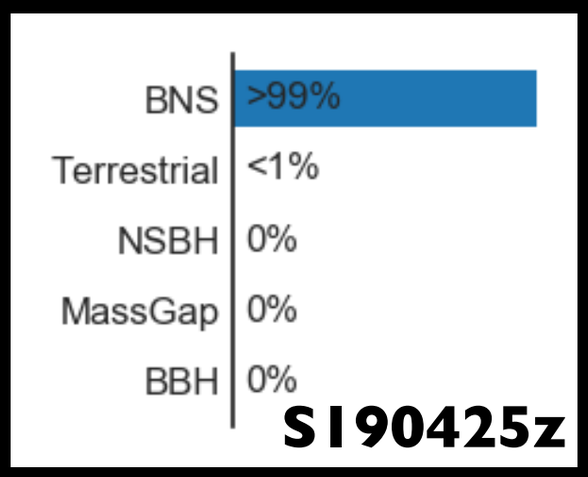
Observing run O3

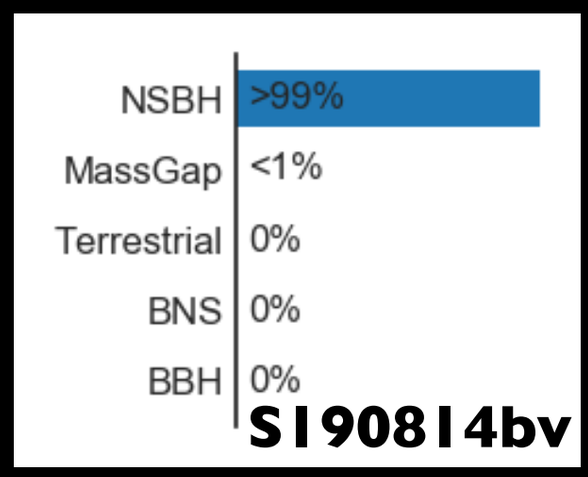
Sum of probabilities in each category

- ~35 BBH
- ~4.5 NSBH
- ~4.5 BNS
- ~3 Gap
- ~6 Terr









https://emfollow.docs.ligo.org/userguide/

- No multi-messenger counterparts so far

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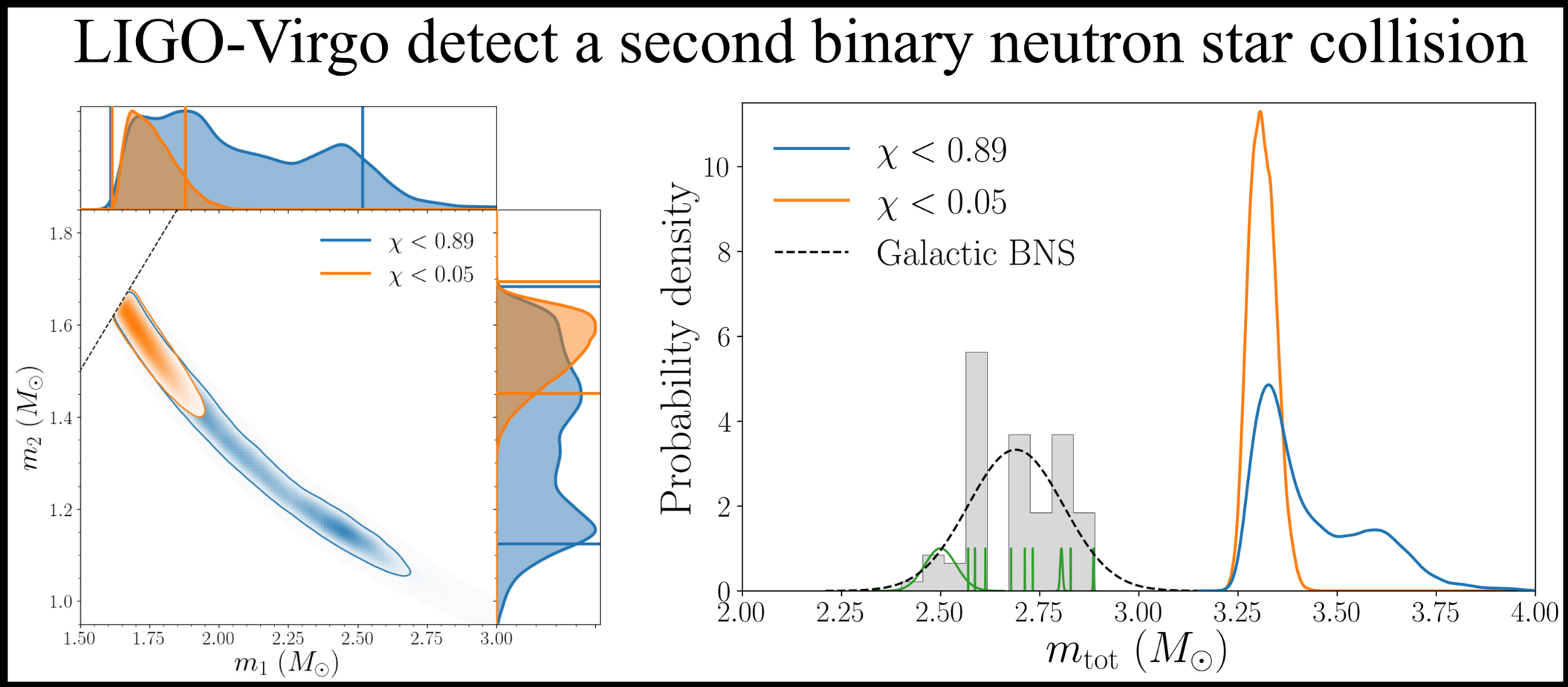
GW190425

- Most likely second binary neutron star
- Identified in single detector analysis
- Mass is outlier relative to Galactic population



Abbott et al., GW190425: Observation of a Compact Binary Coalescence with Total Mass ~ 3.4 Msun, arXiv:2001.01761. To appear in ApJL

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Publication Plans

- S190412m: Release in ~Mar/Apr 2020
- S190521g: Release in ~Mar/Apr 2020
- S190814bv: Release ~Mar/Apr 2020
- GWTC-2: Release ~ April 2020

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2020s

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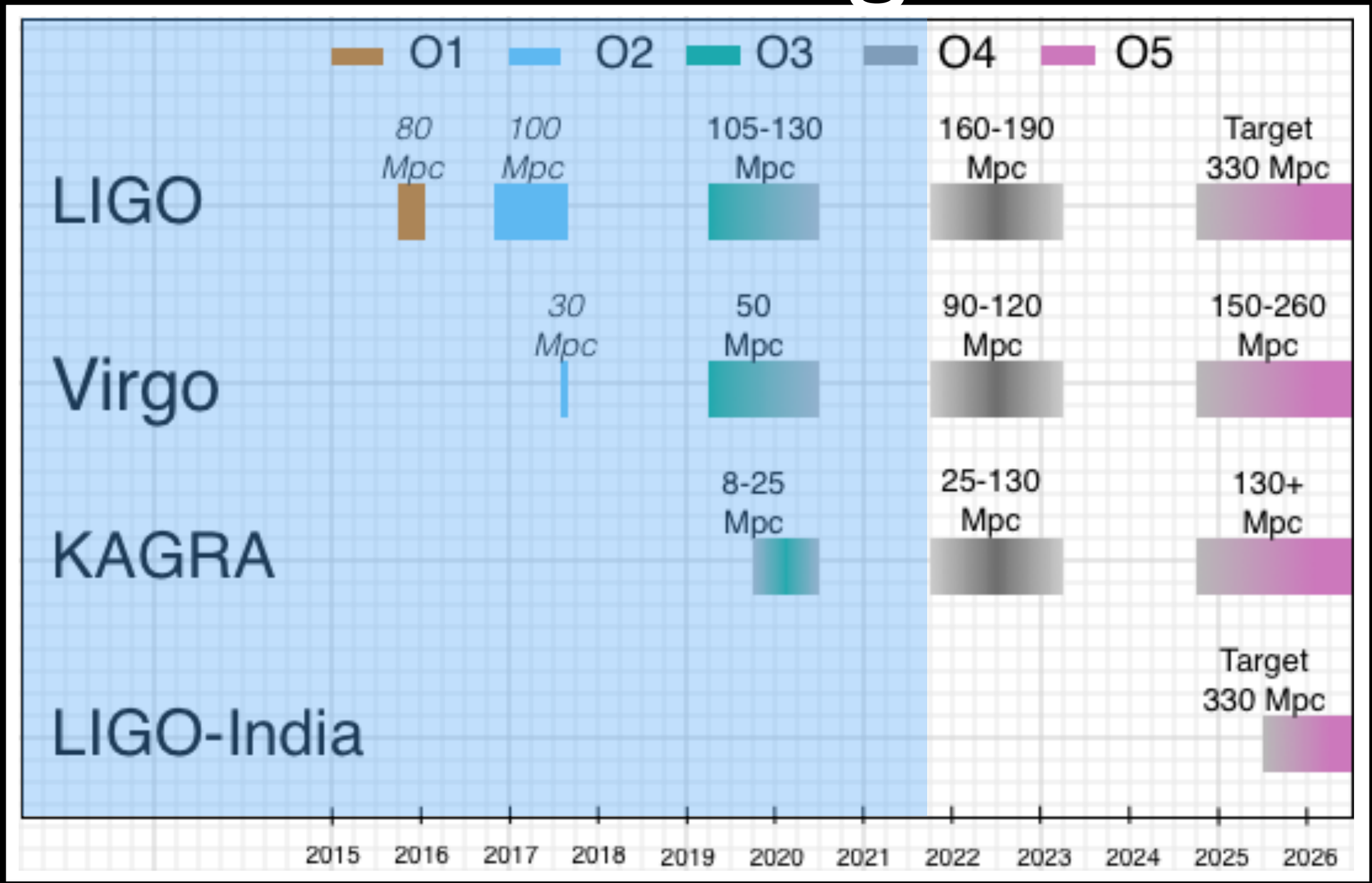
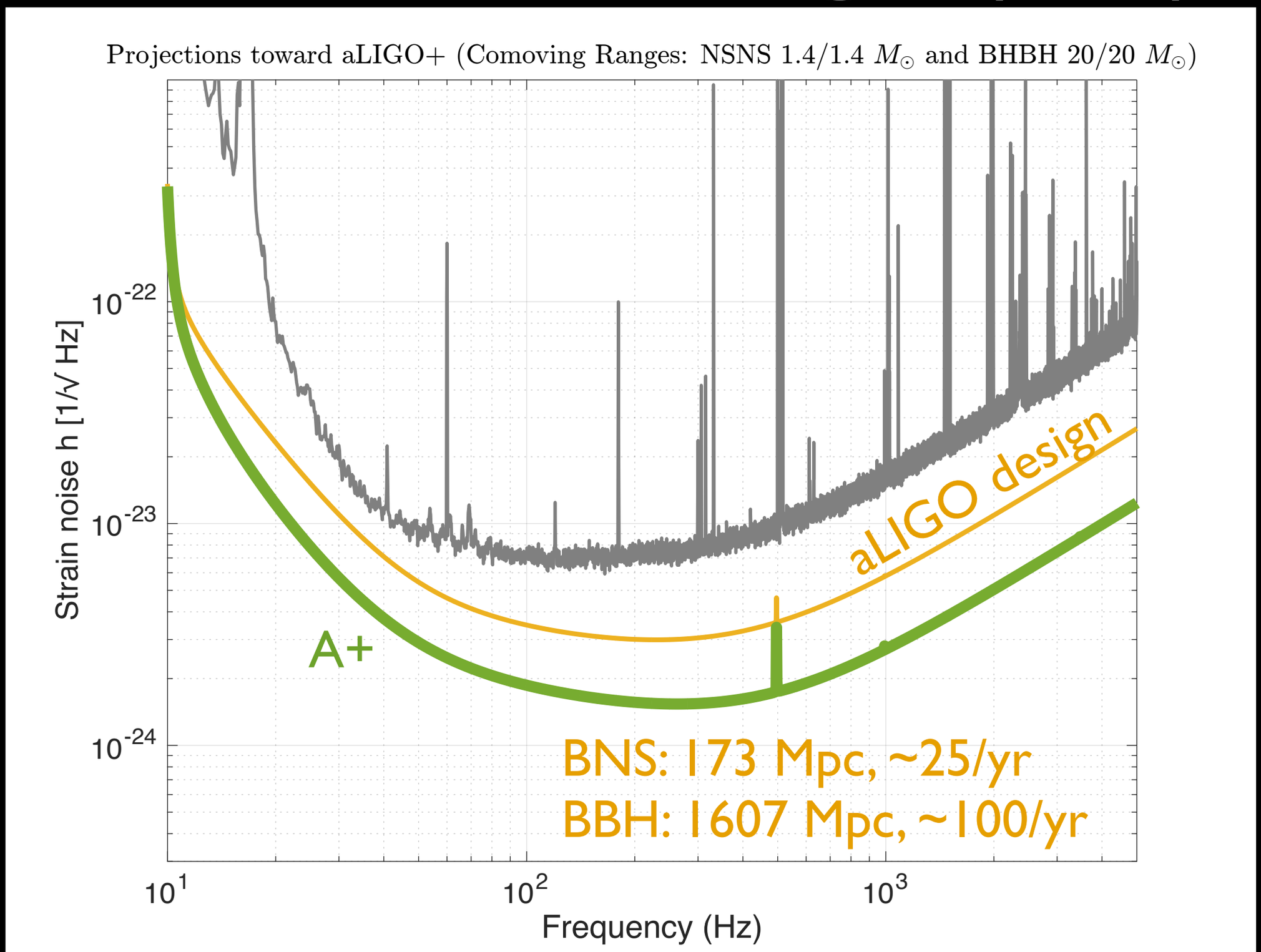
Observing runs



LIGO-Virgo-KAGRA Collaborations, Prospects for Localizing Gravitational-wave Transients … , arXiv:1304.0670

aLIGO Design (O4)



Credit: LIGO Laboratory / A+ Team / D. Reitze

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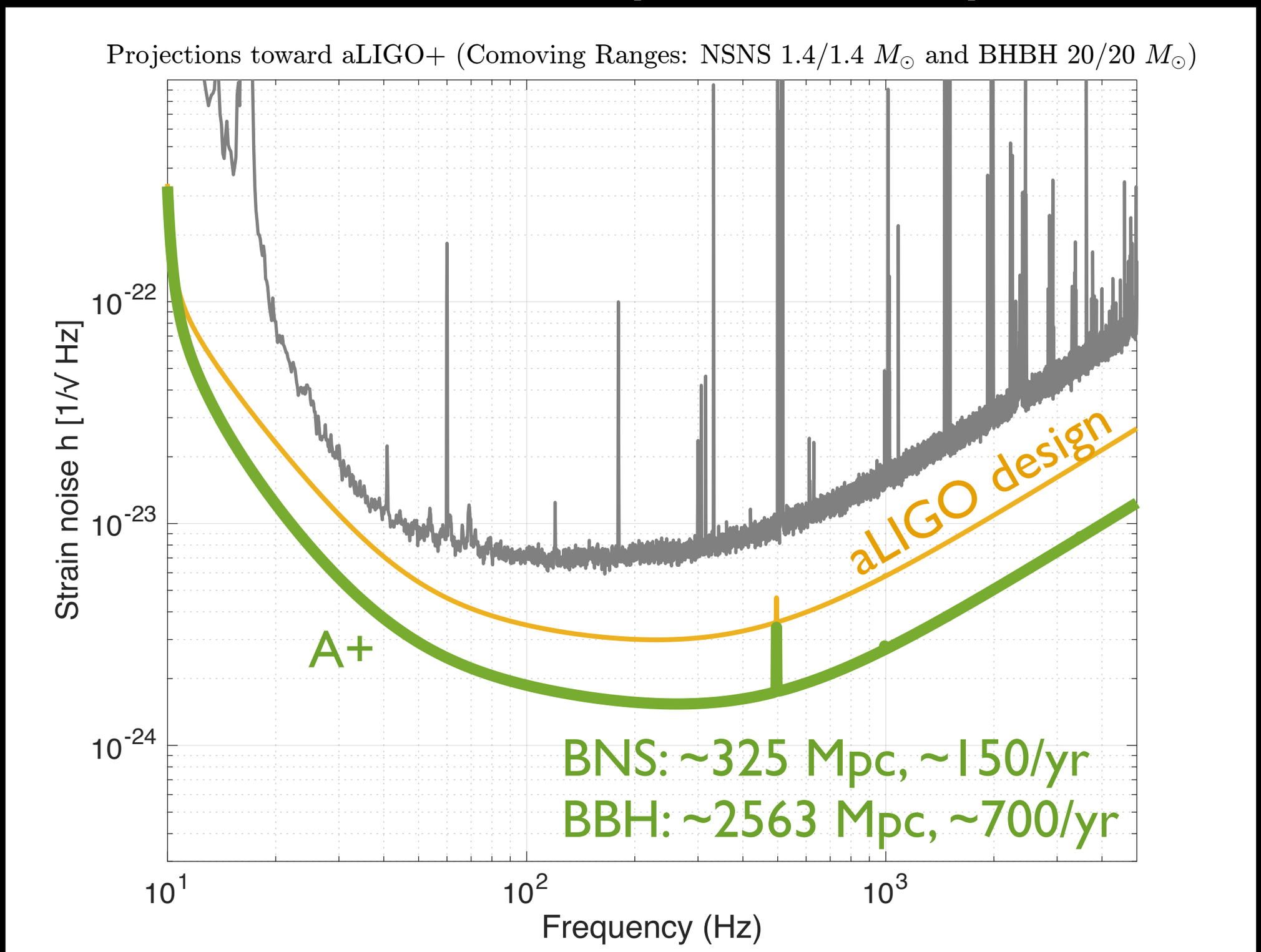
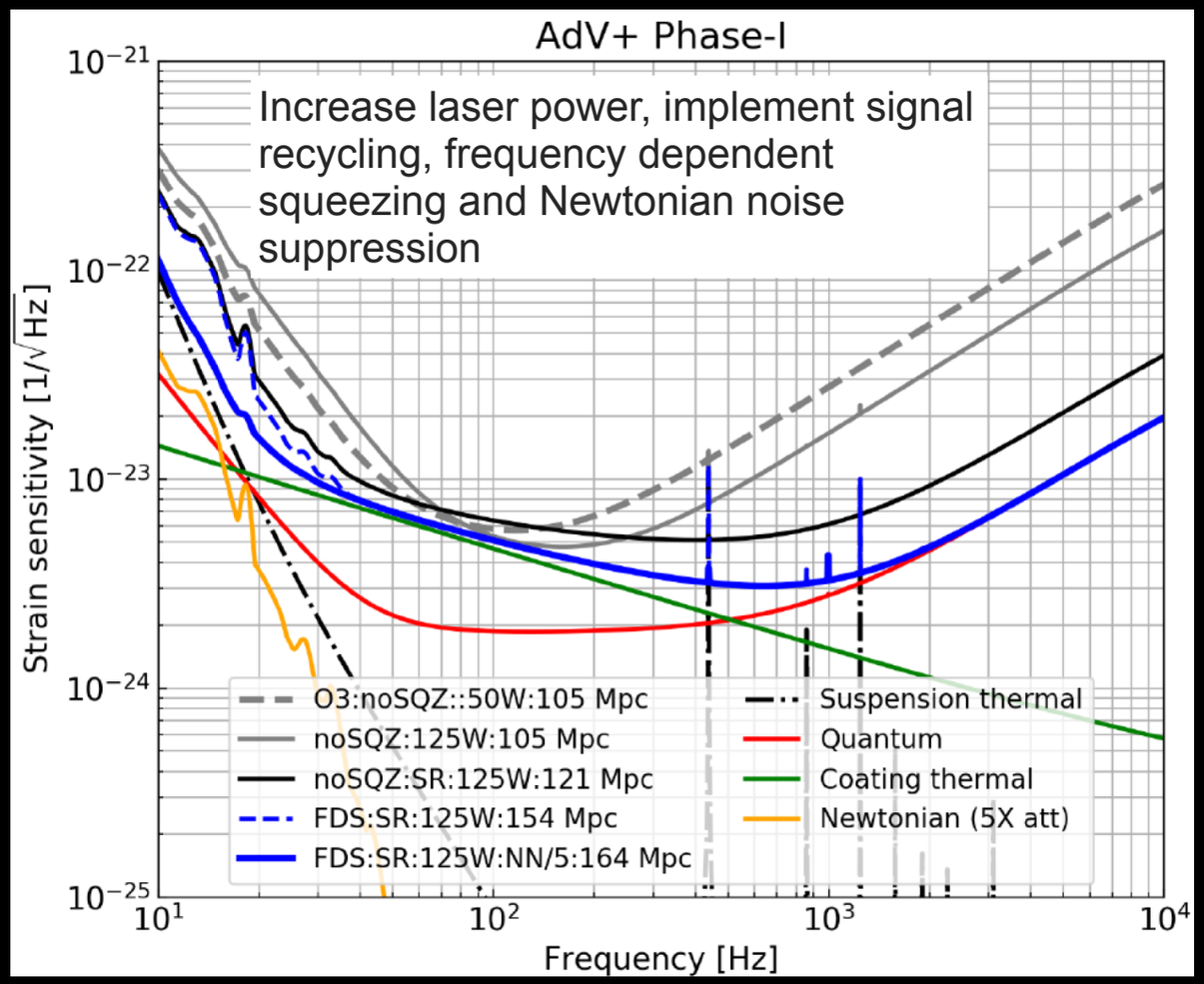
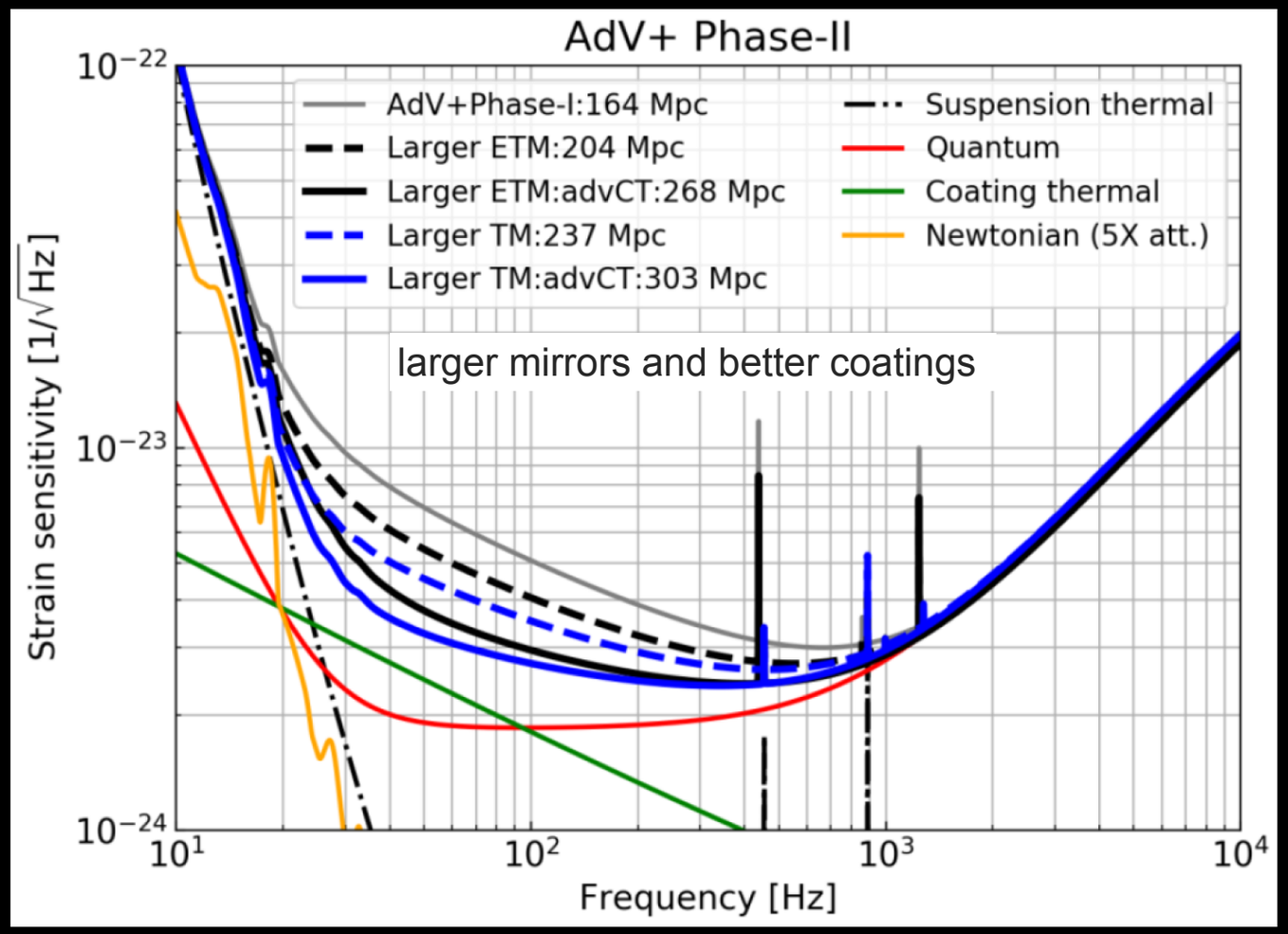
A+ (~2025)



Credit: LIGO Laboratory / A+ Team / D. Reitze

AdV+ (~2025)





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IGWN 2030 and Beyond

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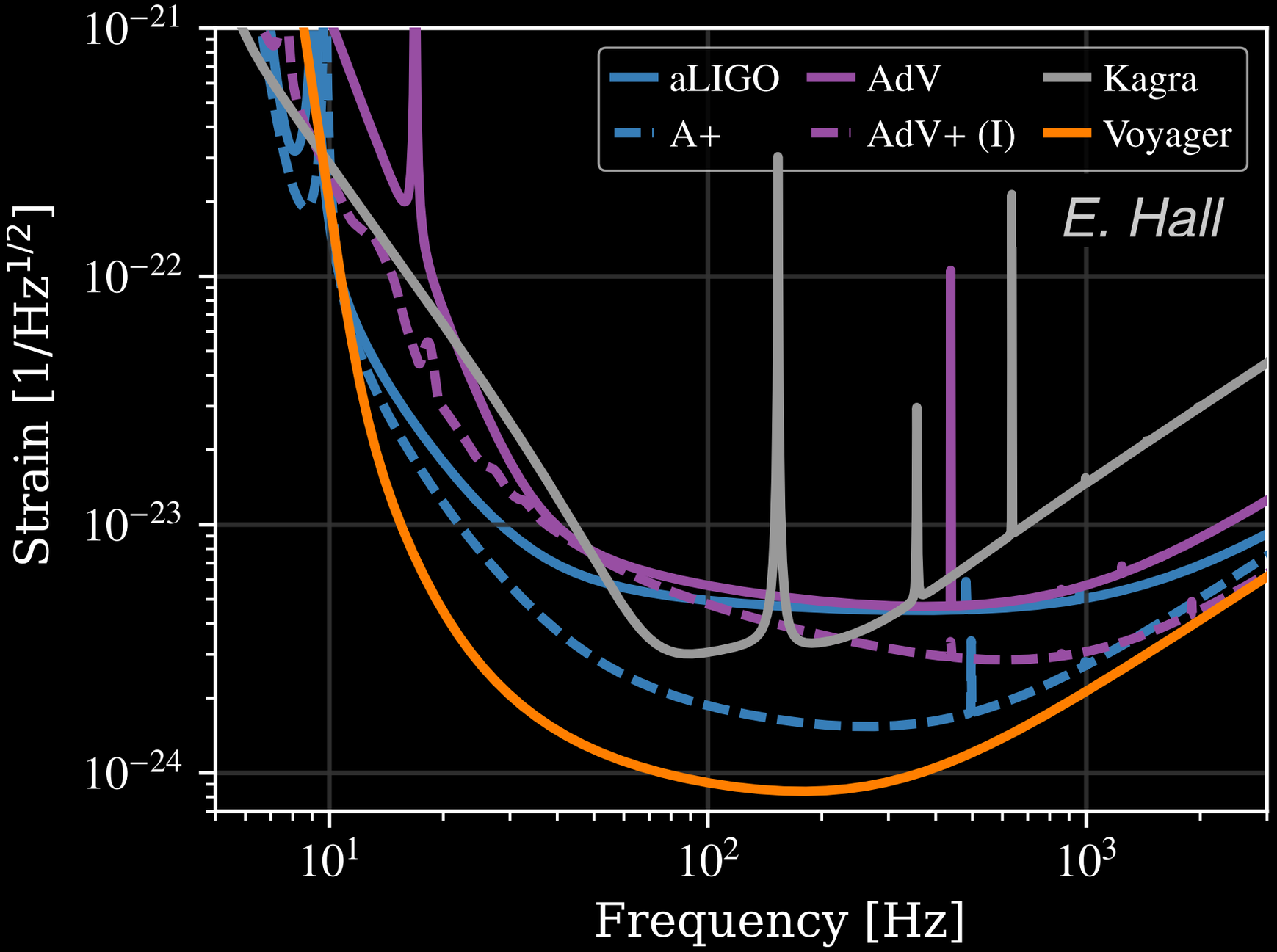
Voyager



- Conceptual design for detectors in current facilities
- ~10,000 binary coalescences per day

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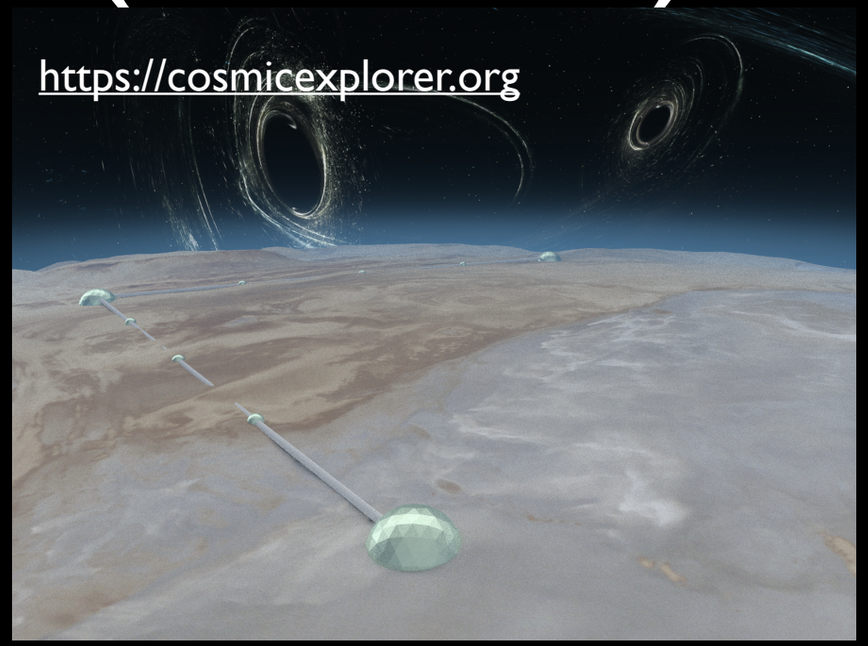
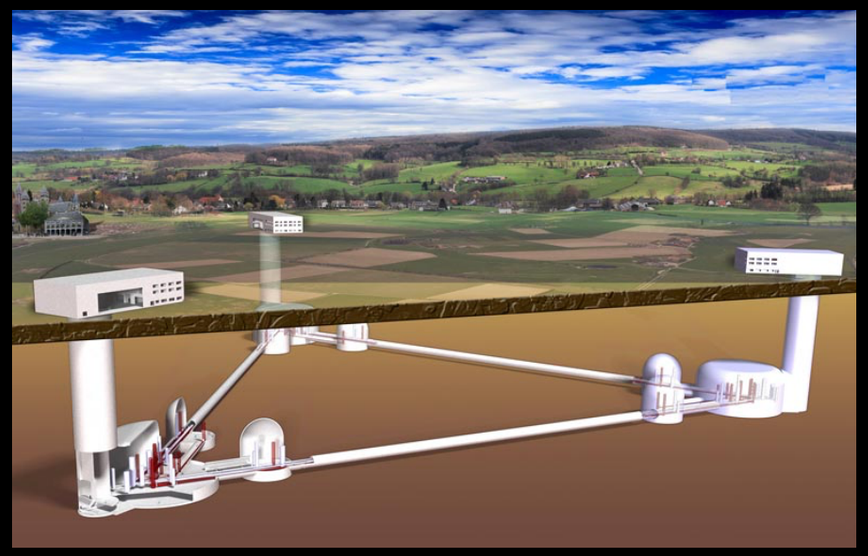
LIGO 3rd Generation (~2035)

- Cosmic Explorer
  - NSF-funded US conceptual design study
  - 40km surface observatory
  - Stage 1 (~2035): extension of A+
  - Stage 2 (~2045): cryogenic, new test masses, coatings, …
- Einstein Telescope
  - European conceptual design study
  - 10km, triangle, multi-detector, underground
  - 10-15 year technology development

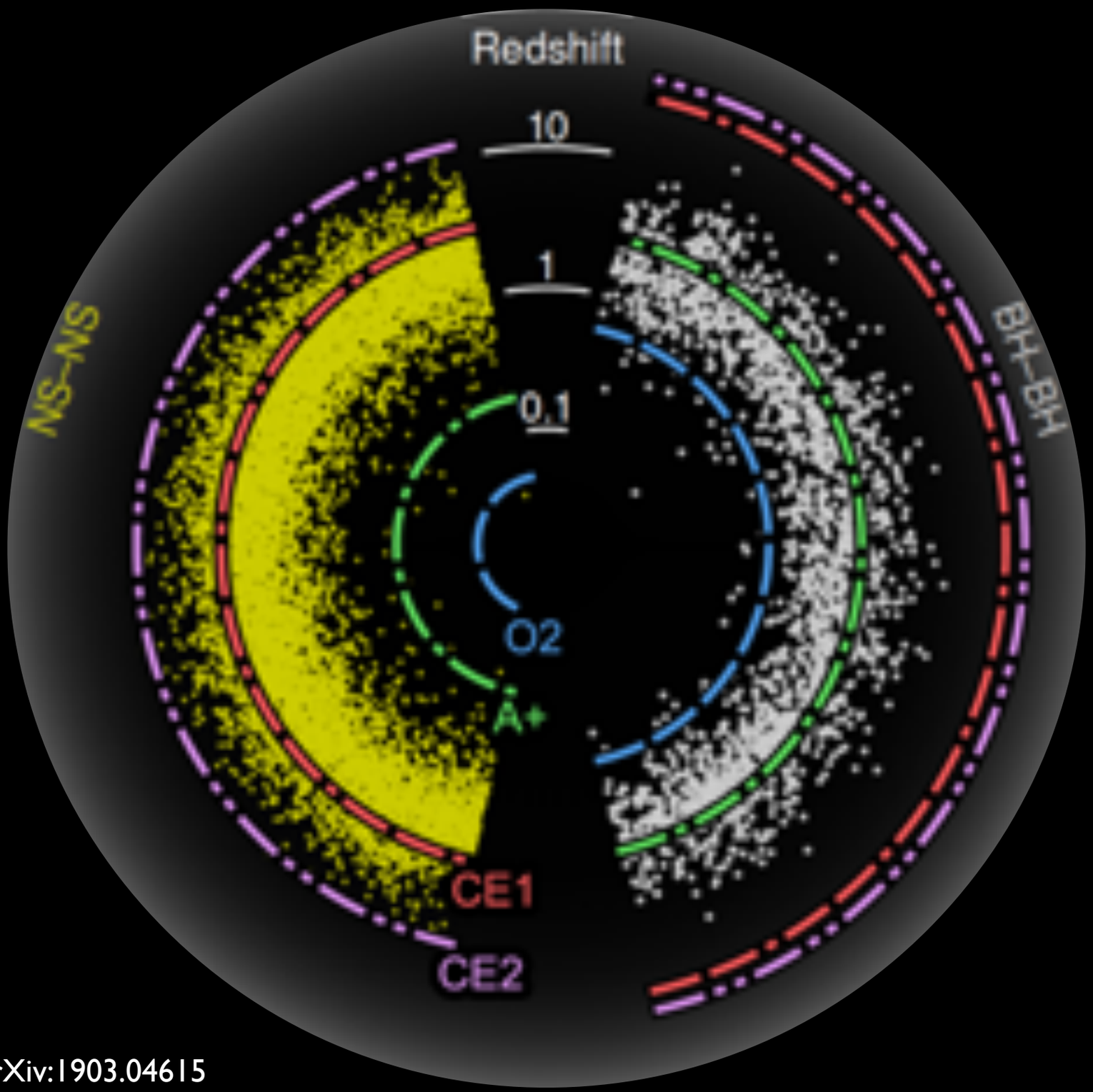




http://www.et-gw.eu/

Gravitational-wave International Committee, 3G Subcommittee
https://gwic.ligo.org/3Gsubcomm/documents.shtml

LIGO Sensitivity to Binary Mergers



Credit: D. Reitze et al, arXiv:1903.04615

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Thank you!