Paris Centre for Cosmological Physics

PCCP LECTURES COURSE

The physics of KAGRA Gravitational Wave detector

Cosmology and astrophysics with LIGO/VIRGO and KAGRA

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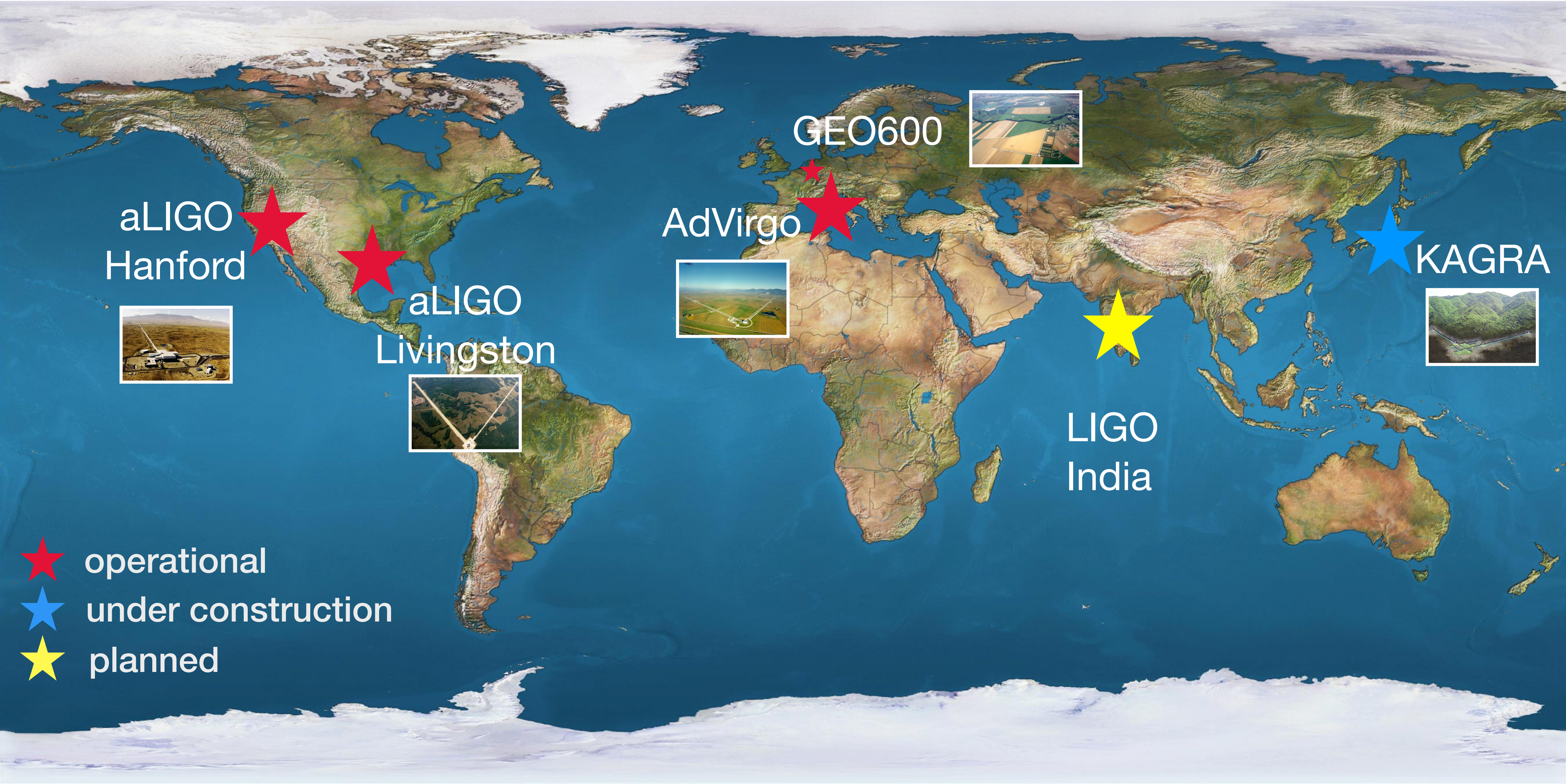
APC January 2018

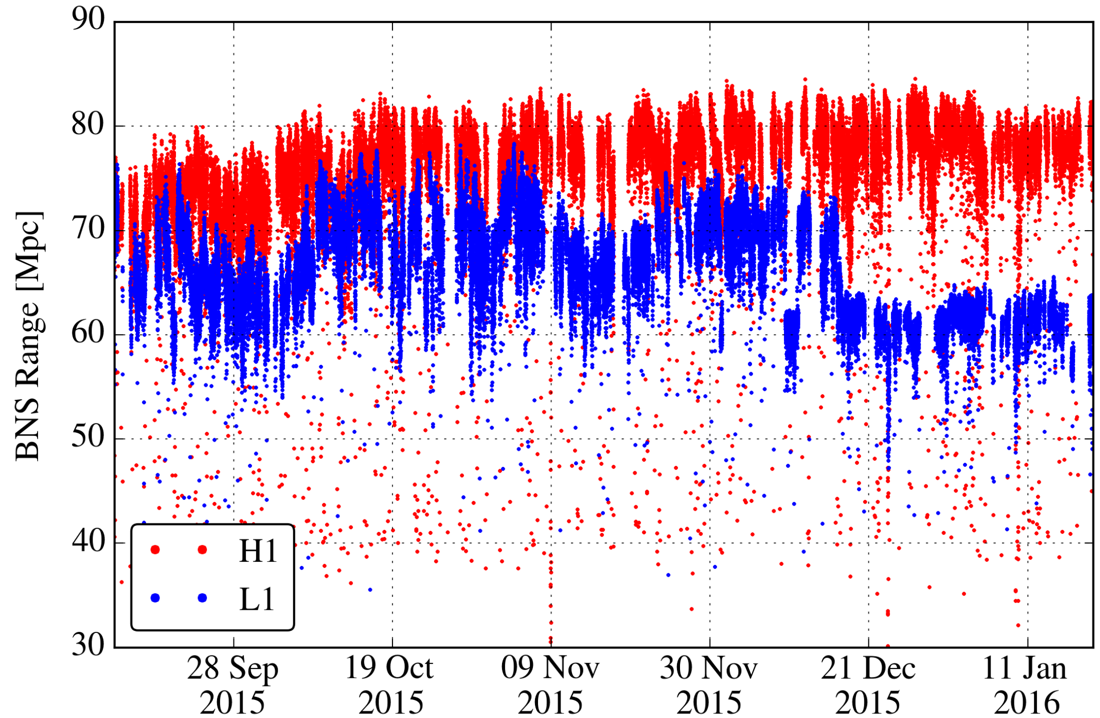
Second generation GW detector network



Observation runs up to now

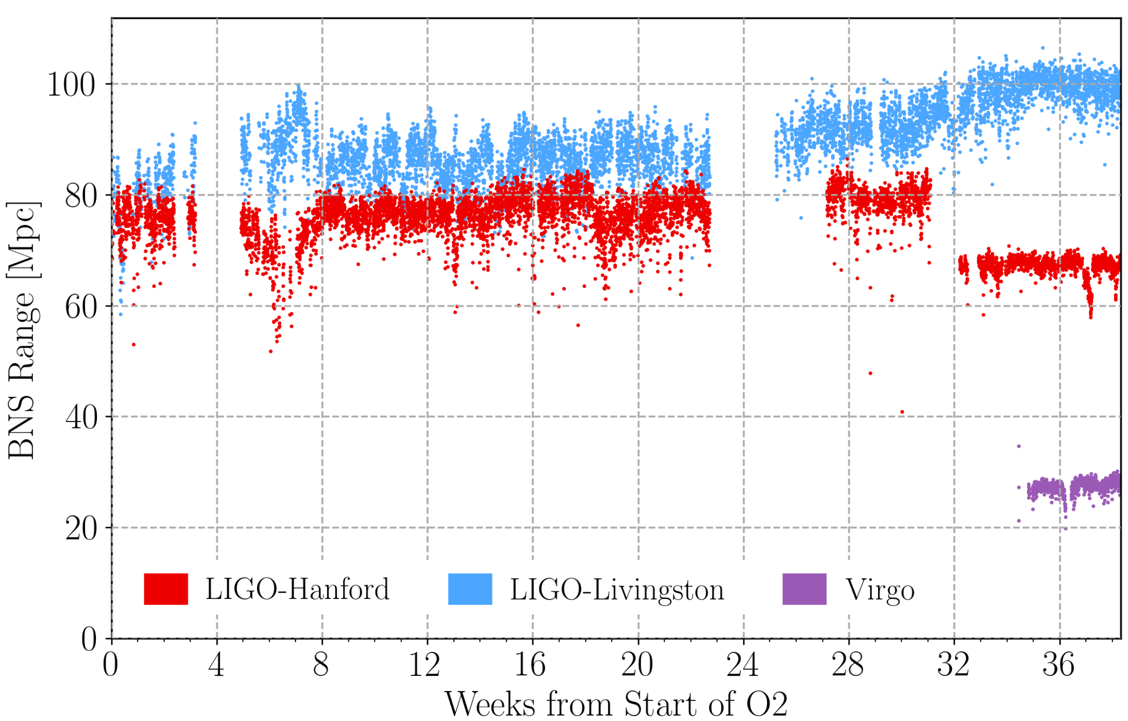
- O1: ~4 months [09/15-01/16], range : 60-80 Mpc
- O2: ~9 months [12/16-08/17], range : 70-100 Mpc + Virgo (25-30 Mpc) from 01/08

O1



Martynov et al.
Phys. Rev. D **93**, 112004

O2



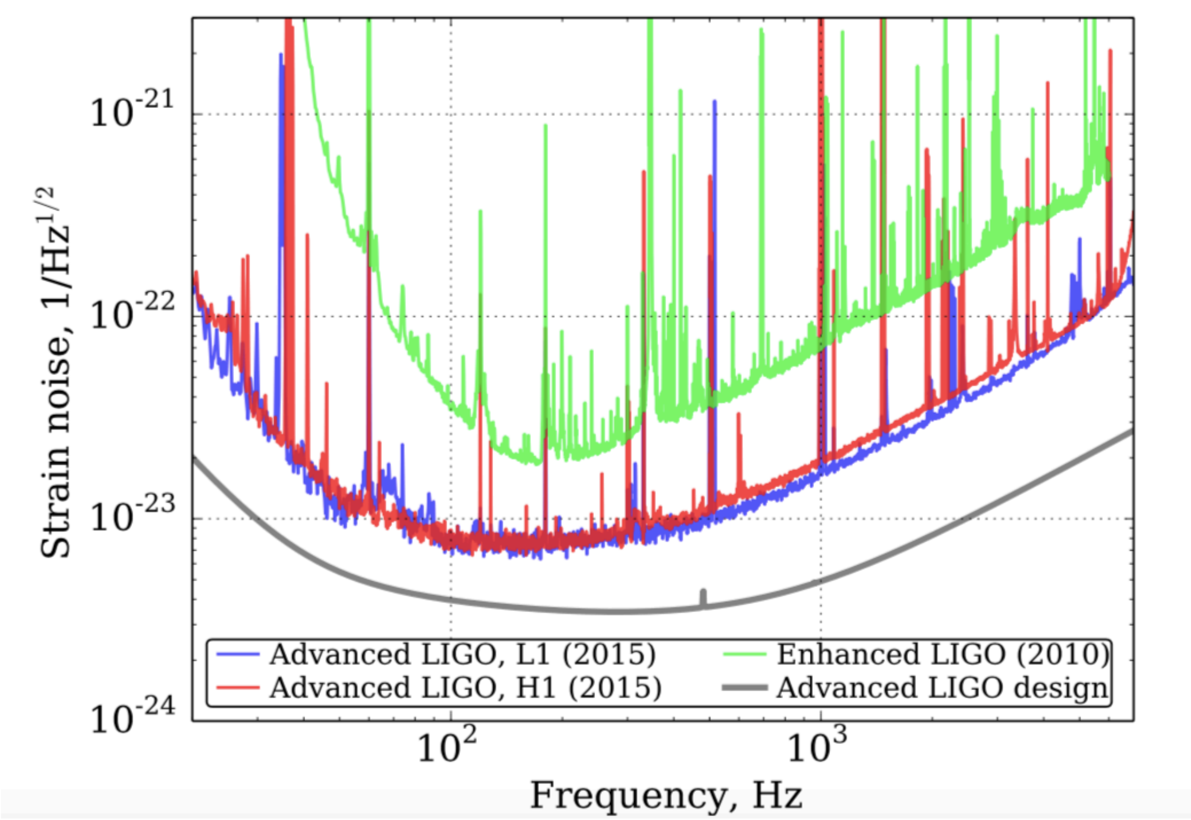
arXiv:1811.12907

Range: distance to which a single instrument could detect a 1.4M⊙-1.4M⊙BNS merger, averaged over sky location and orientation, with an average signal-to-noise ratio (SNR) of 8

Observation runs up to now

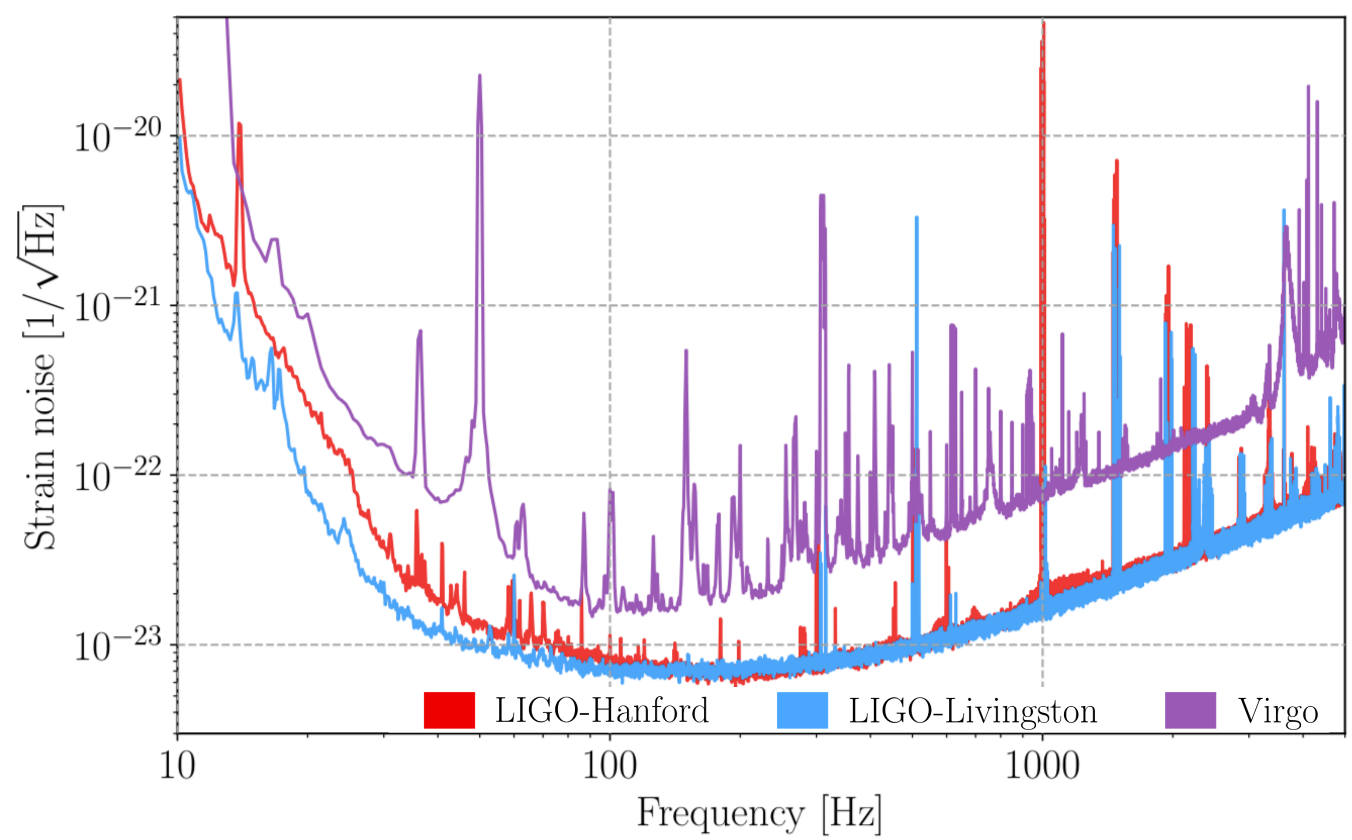
- O1: ~4 months [09/15-01/16], range : 60-80 Mpc
- O2: ~9 months [12/16-08/17], range : 70-100 Mpc + Virgo (25-30 Mpc) from 01/08

O1



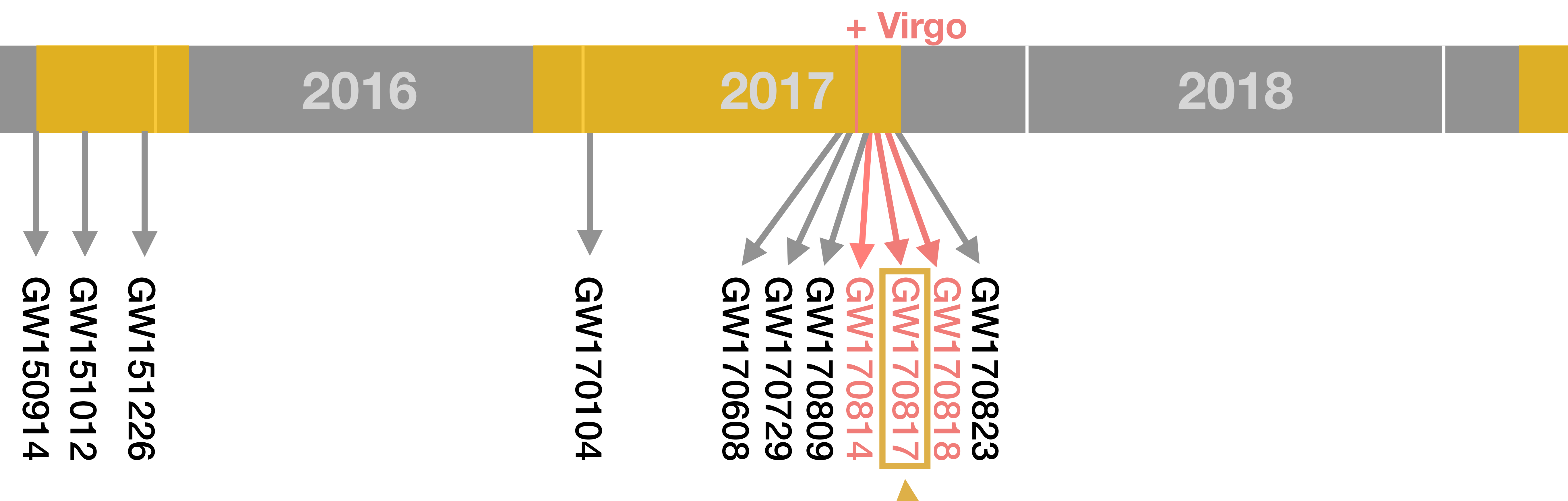
Phys. Rev. D **93**, 112004

O2



arXiv:1811.12907

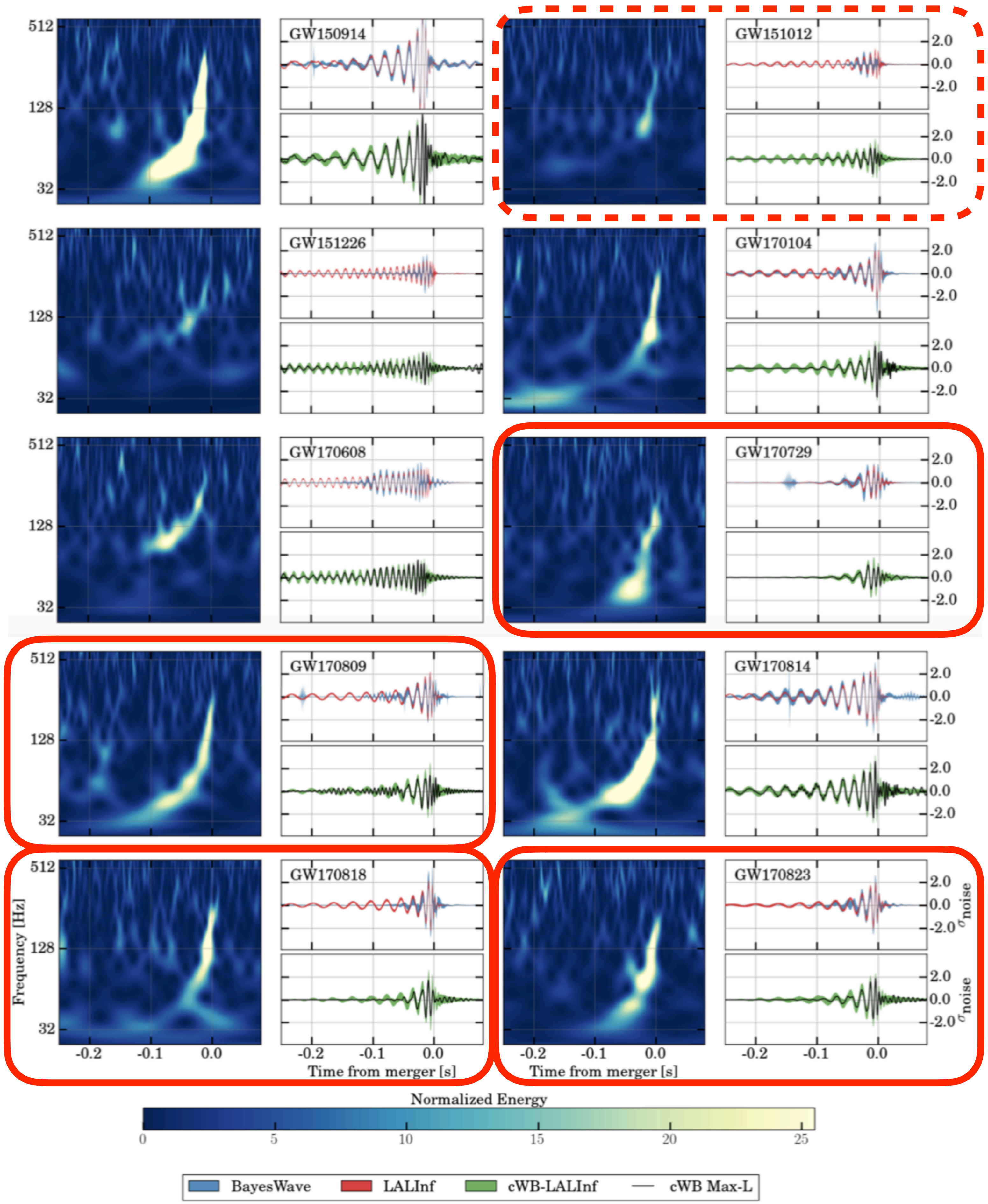
Detections up to now



- **1 Binary Neutron Star merger**
- **10 Binary Black Hole merger**

GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs arXiv:1811.12907

Four new BBH merger identified



Offline noise subtraction for Advanced LIGO

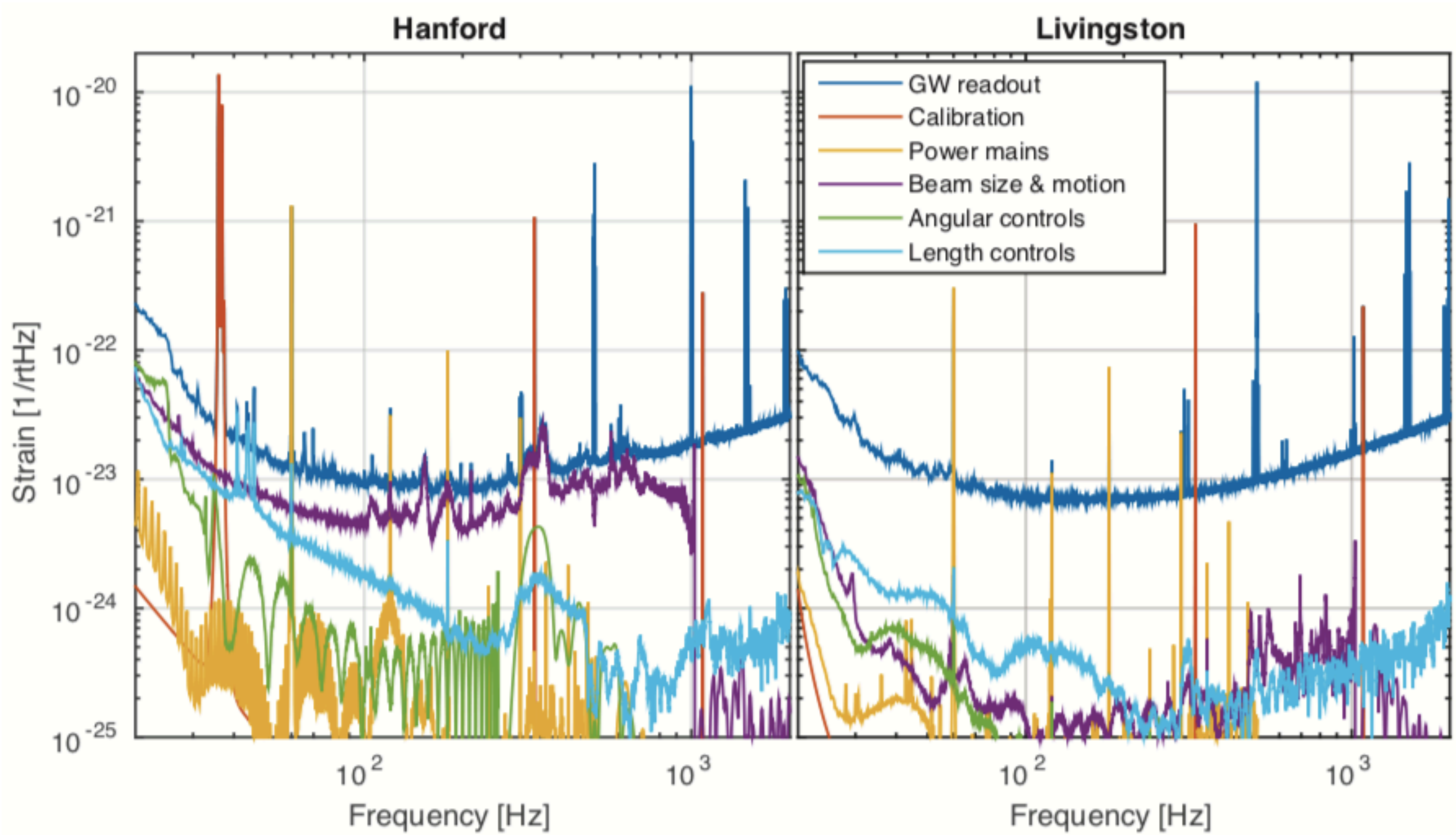
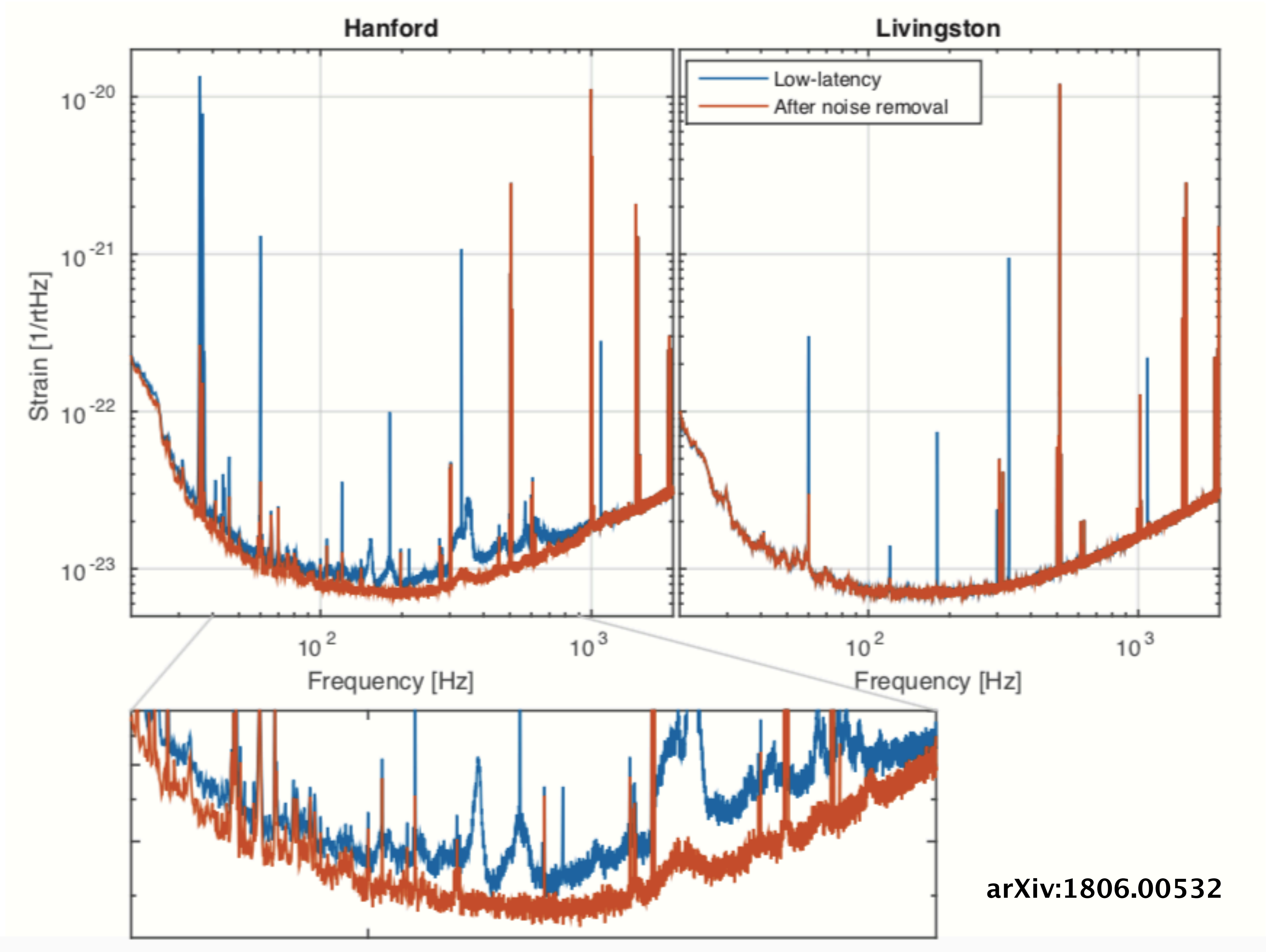


FIG. 1. Noise amplitude spectral density of the Advanced LIGO detectors (dark blue) with the left panel for Hanford and the right panel for Livingston. The other traces are the estimated contributions of the calibration lines (red), power line and harmonics (gold), beam jitter motion and beam size variations (purple), angular control noise (green), and the auxiliary length controls degree of freedom (light blue). These spectra are based on 1024 s of data starting on 25 June 2017 at 08:00:00 UTC, at a time when both LIGO interferometers were operating and in an observation ready state.

arXiv:1806.00532

Offline noise subtraction for Advanced LIGO



arXiv:1806.00532

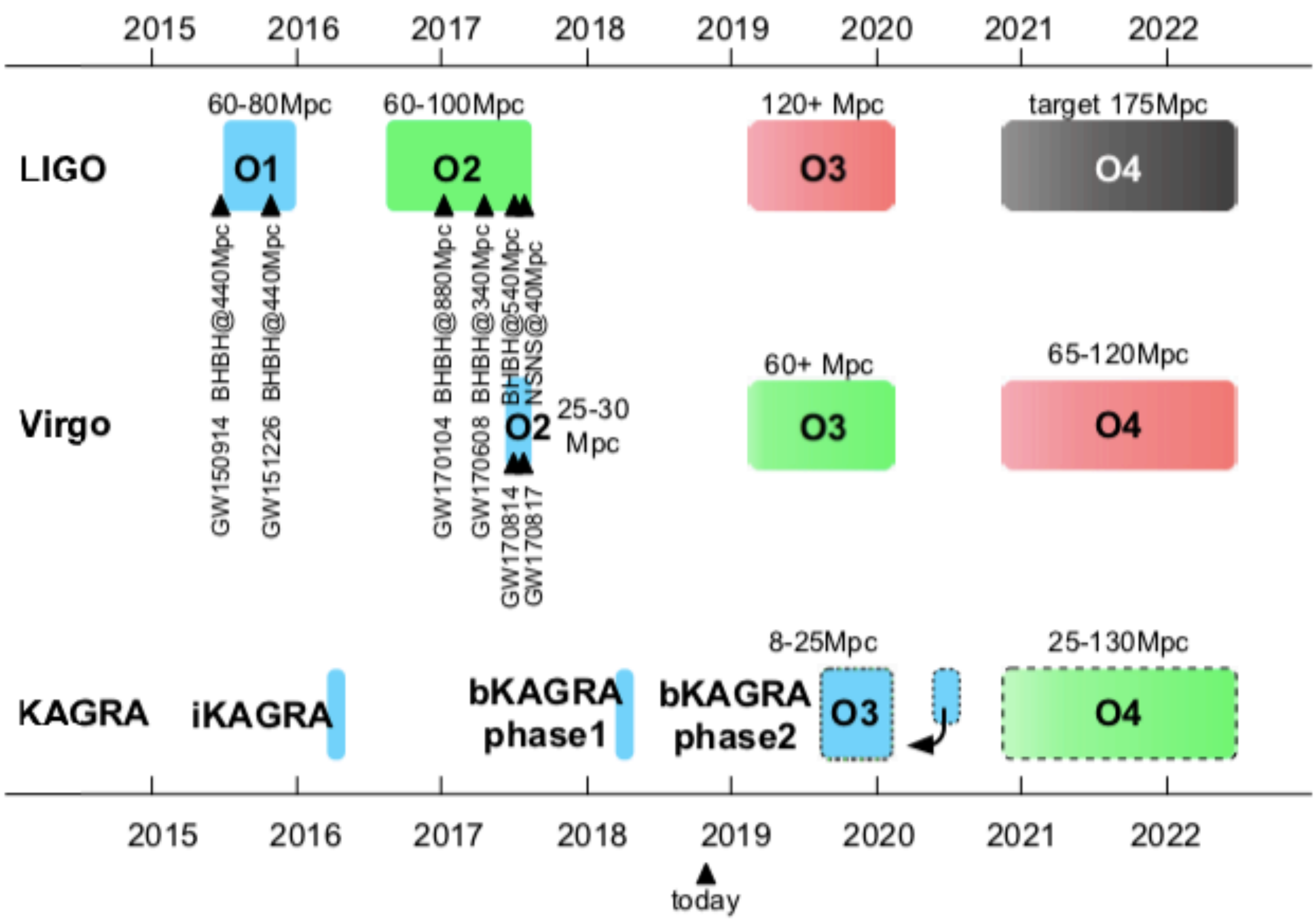
Summary of sources parameters

Event	$m_1/\mathrm{M}_\odot$	$m_2/\mathrm{M}_\odot$	$\mathcal{M}/\mathrm{M}_\odot$	χ_{eff}	$M_{\mathrm{f}}/\mathrm{M}_\odot$	a_{f}	$E_{\mathrm{rad}}/(\mathrm{M}_\odot c^2)$	$\ell_{\mathrm{peak}}/(\mathrm{erg\,s^{-1}})$	$D_{\mathrm{L}}/\mathrm{Mpc}$	z	$\Delta\Omega/\mathrm{deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4} \times 10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	179
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.8}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7} \times 10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1476
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7} \times 10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1033
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.4^{+5.2}_{-3.9}$	$0.66^{+0.09}_{-0.11}$	$2.2^{+0.5}_{-0.5}$	$3.2^{+0.7}_{-1.0} \times 10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	924
GW170608	$11.2^{+5.4}_{-1.9}$	$7.5^{+1.5}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.04^{+0.19}_{-0.06}$	$17.9^{+3.4}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.8^{+0.1}_{-0.1}$	$3.4^{+0.5}_{-1.3} \times 10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	396
GW170729	$50.7^{+16.3}_{-10.2}$	$34.4^{+8.9}_{-10.2}$	$35.8^{+6.3}_{-4.9}$	$0.37^{+0.21}_{-0.26}$	$80.3^{+14.5}_{-10.3}$	$0.81^{+0.07}_{-0.13}$	$4.9^{+1.6}_{-1.7}$	$4.2^{+0.8}_{-1.5} \times 10^{56}$	2760^{+1290}_{-1350}	$0.48^{+0.18}_{-0.21}$	1069
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9} \times 10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	340
GW170814	$30.7^{+5.3}_{-3.0}$	$25.6^{+2.7}_{-4.1}$	$24.3^{+1.4}_{-1.1}$	$0.07^{+0.13}_{-0.11}$	$53.6^{+3.2}_{-2.5}$	$0.73^{+0.07}_{-0.05}$	$2.8^{+0.4}_{-0.3}$	$3.7^{+0.5}_{-0.5} \times 10^{56}$	560^{+140}_{-210}	$0.12^{+0.03}_{-0.04}$	87
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1 \times 10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	16
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.8}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7} \times 10^{56}$	1020^{+430}_{-360}	$0.20^{+0.07}_{-0.07}$	39
GW170823	$39.5^{+10.1}_{-6.6}$	$29.4^{+6.5}_{-7.1}$	$29.3^{+4.2}_{-3.1}$	$0.08^{+0.19}_{-0.22}$	$65.6^{+9.3}_{-6.5}$	$0.71^{+0.08}_{-0.09}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9} \times 10^{56}$	1860^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1628

GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs

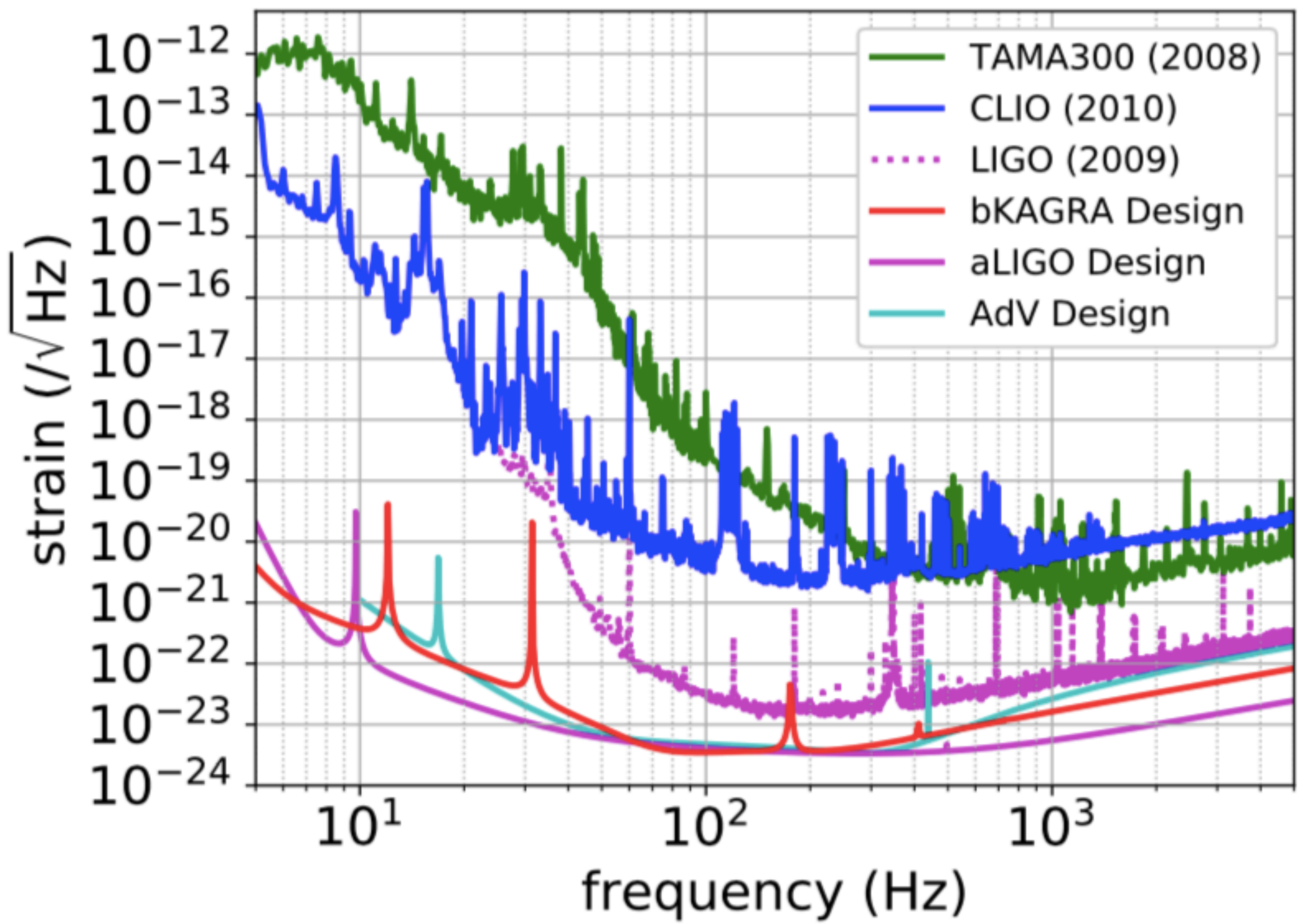
ArXiv:1811.12907

Planned observation runs



“KAGRA: 2.5 generation interferometric gravitational wave detector”
Nature Astronomy volume 3 5–40 (2019)

Expected sensitivities



"KAGRA: 2.5 generation interferometric gravitational wave detector"
Nature Astronomy volume 3 5–40 (2019)

What can we do with 2nd generation GW detector network?

- PHYSICS
- ASTROPHYSICS
- COSMOLOGY

Physics with gravitational waves

- Test General Relativity
  - GW waveforms[1]
  - GW polarizations[2]
  - GW speed[3]

1 "Tests of general relativity with GW150914"
Phys. Rev. Lett. 116, 221101 (2016)

2 "GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence"
Phys. Rev. Lett. **119**, 141101

3 "Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A"
The Astrophysical Journal Letters, Volume 848, Number 2

Some astrophysics with gravitational waves

- Binary masses, spin and rate -> formation and evolution of compact binaries and of their components
- Neutron stars equation of state
- Origin of short GRB
- Detection of EM counterpart (and associated phenomena) thanks to a precise localization
- Other sources than compact binaries ?

What is the origin of compact binary systems?

Two main scenarios:

- Isolated binary evolution in galactic fields
- Dynamical formation in dense star clusters

Population properties (e.g mass, spin, rate) potentially allows to discriminate between different scenarios

Masses of compact objects

- Stellar mass distribution is smooth and covers a range from ~ 0.1 $M_\odot$ to few hundred $M_\odot$
- Remnants distribution could have gaps:
  - NS $\leq 2.5\ M_\odot$ BH $\geq 5\ M_\odot$ → origin and existence not clear
  - no BH between 60 $M_\odot$ and 120 $M_\odot$ → predicted by pair-instability supernova model
- We have a low statistics: 20 BH and 50 NS (from EM observation)
- **GW observation of compact objects can confirm/ disprove the presence of these gaps** (still some doubt about possible EM observation bias)

Masses extrapolation

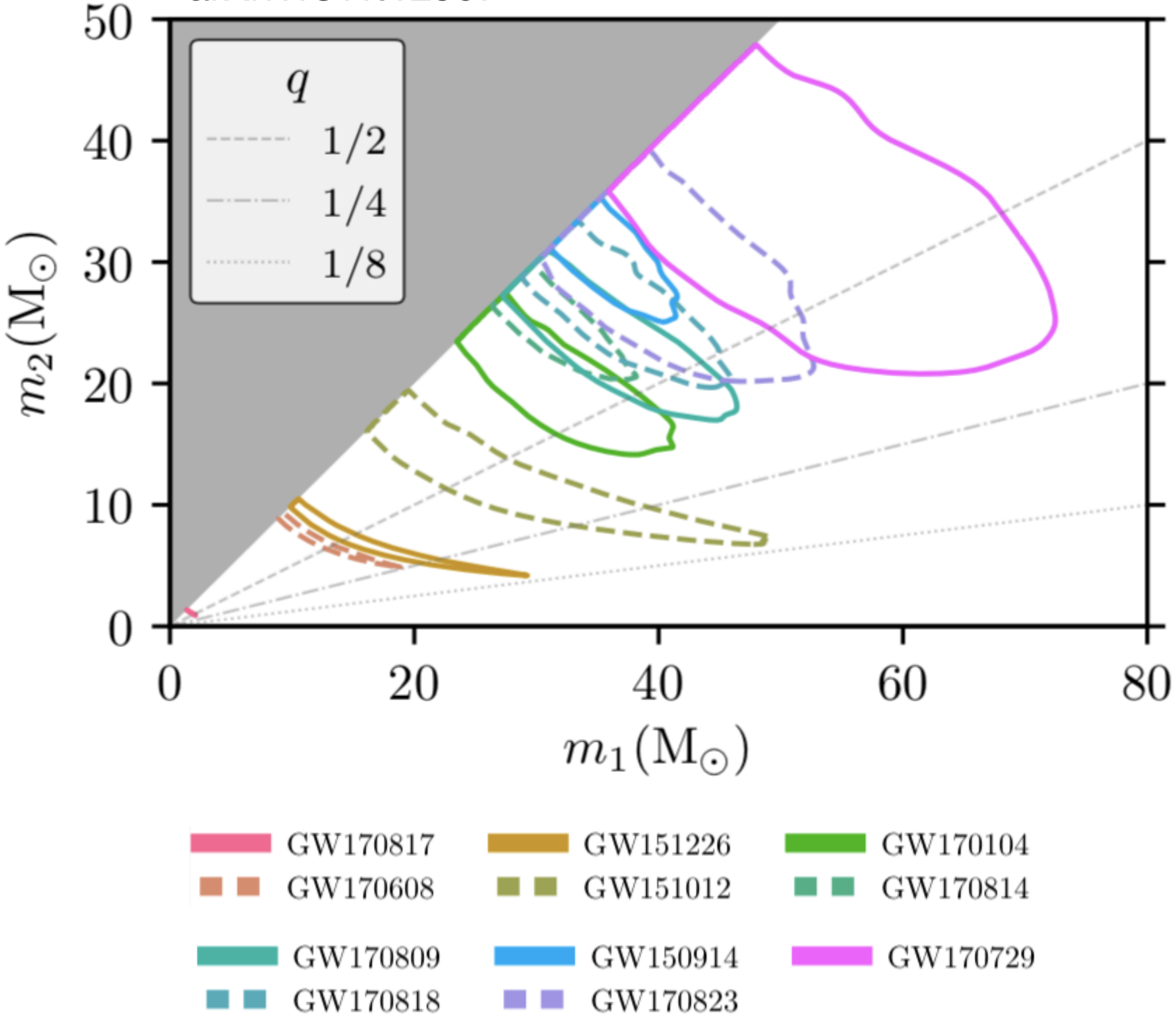
- **Chirp Mass** determines the GW phase at the leading order of PN expansion

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

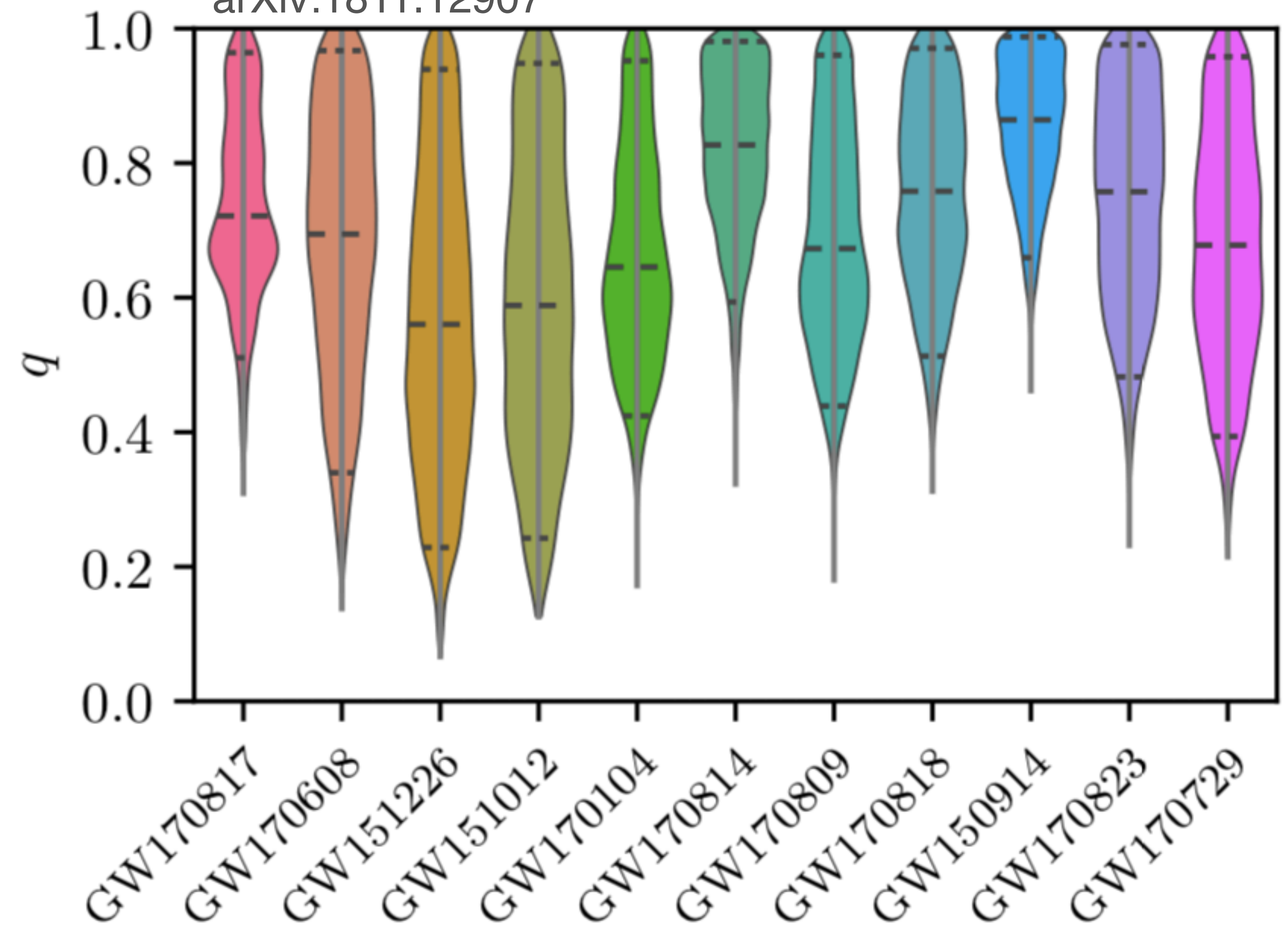
- **Mass Ratio** appears in higher orders

$$q = \frac{m_1}{m_2}$$

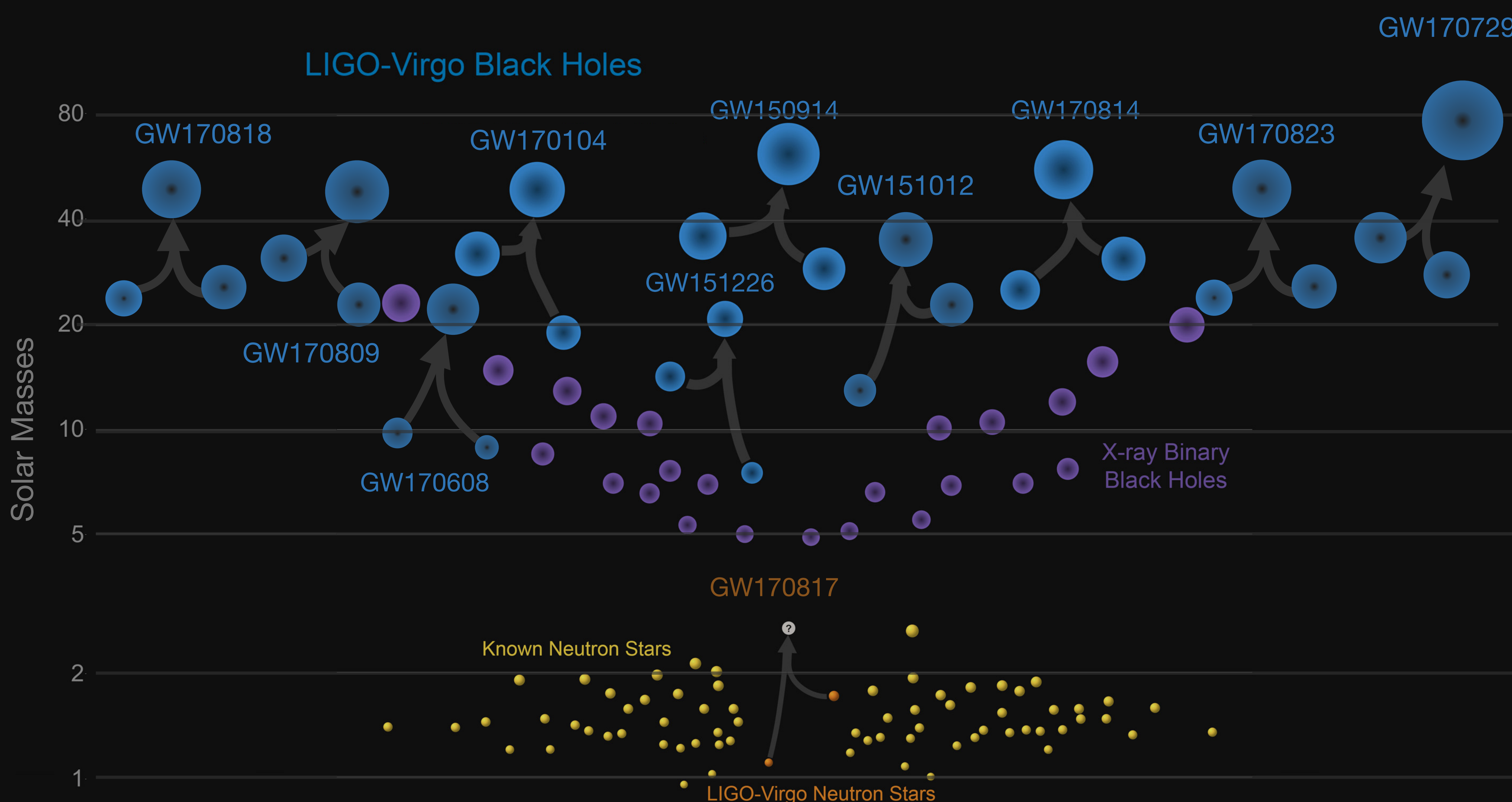
arXiv:1811.12907



arXiv:1811.12907



Known compact object masses



adapted from ligo.caltch.edu

Masses: preliminar results

Event	$m_1/\mathrm{M}_\odot$	$m_2/\mathrm{M}_\odot$	$M_\mathrm{f}/\mathrm{M}_\odot$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$63.1^{+3.3}_{-3.0}$
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$35.7^{+9.9}_{-3.8}$
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$20.5^{+6.4}_{-1.5}$
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$49.4^{+5.2}_{-3.9}$
GW170608	$11.2^{+5.4}_{-1.9}$	$7.5^{+1.5}_{-2.1}$	$17.9^{+3.4}_{-0.7}$
GW170729	$50.7^{+16.3}_{-10.2}$	$34.4^{+8.9}_{-10.2}$	$80.3^{+14.5}_{-10.3}$
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$56.4^{+5.2}_{-3.7}$
GW170814	$30.7^{+5.3}_{-3.0}$	$25.6^{+2.7}_{-4.1}$	$53.6^{+3.2}_{-2.5}$
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	≤ 2.8
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$59.8^{+4.8}_{-3.8}$
GW170823	$39.5^{+10.1}_{-6.6}$	$29.4^{+6.5}_{-7.1}$	$65.6^{+9.3}_{-6.5}$

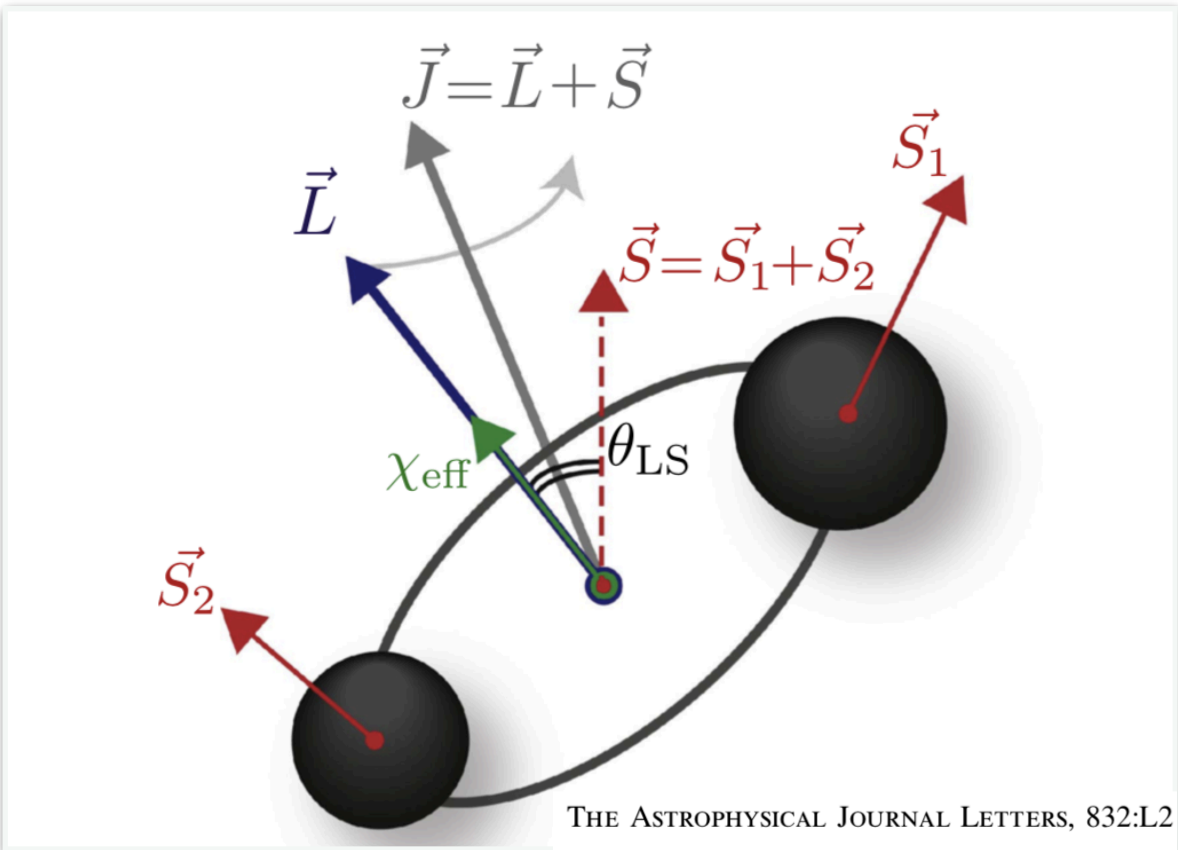
- First observation of “heavy” stellar mass BH (>25 M⊙)
- No masses in the putative gaps
- Some evidence for a build up at the heavy end of the mass spectrum in according to predictions of the pair instability supernova model

Spin alignment VS formation channels

- Binary formed in a dynamic environment should have no preferred direction for the spin

- Isolated binaries are expected to have preferentially spins aligned to the orbital angular momentum but some other mechanisms (e.g. natal kick) could induce a misalignment

Spin orientation



$$\chi_{1,2} = \frac{c}{G m_{1,2}^2} S_{1,2} \cdot \hat{L}$$

$$\chi_{\rm eff} = \frac{m_1 \chi_1 + m_2 \chi_2}{M}$$

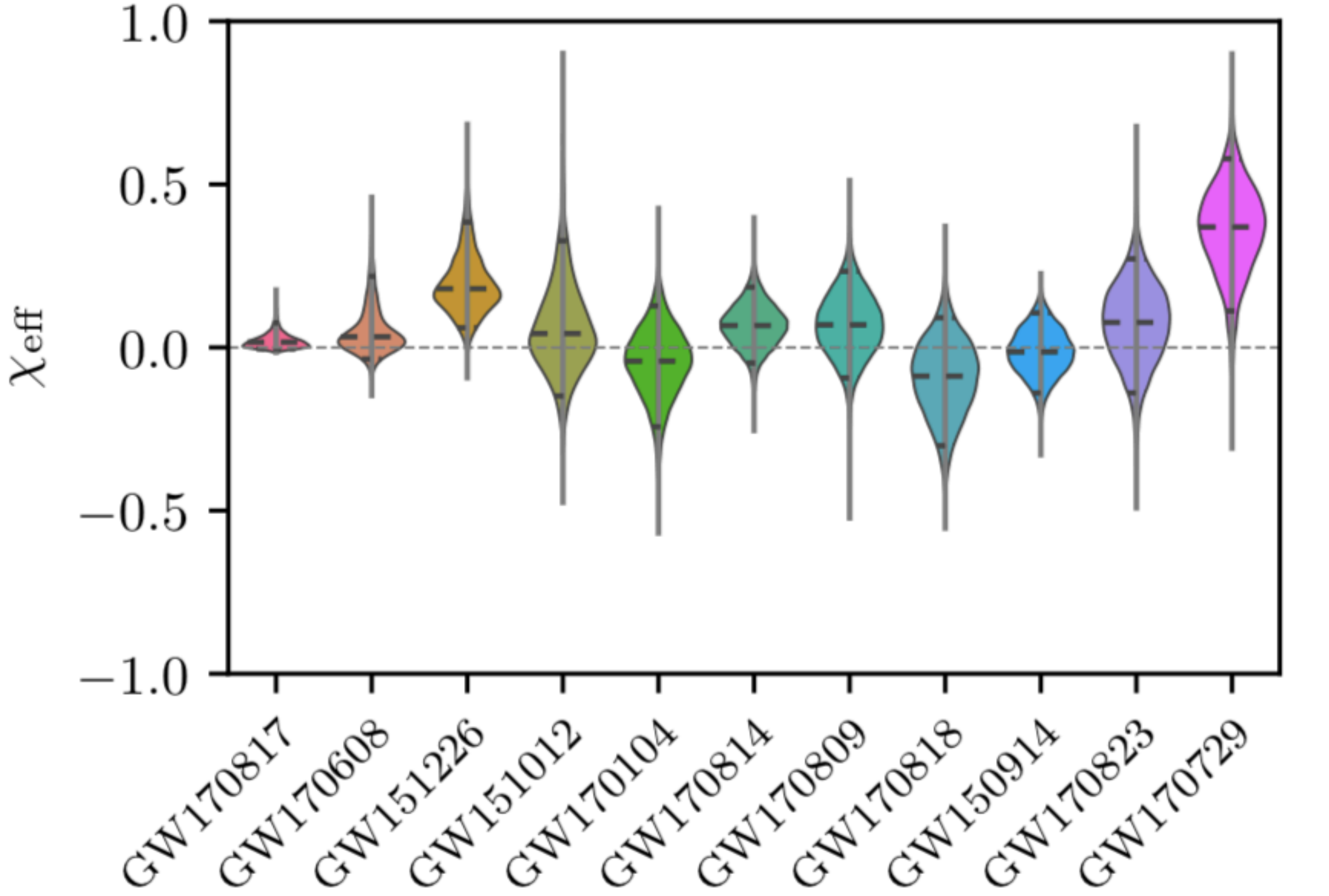
- **Effective spin:** most meaningful parameter for describing the spin effect on the binary phasing: enters in the successive order of the PN expansion

- **Spin components in the orbit plane** cause precession of L about the total angular momentum J. They induces modulations in the amplitude of the GW

Spin orientation: results

Effective aligned spin

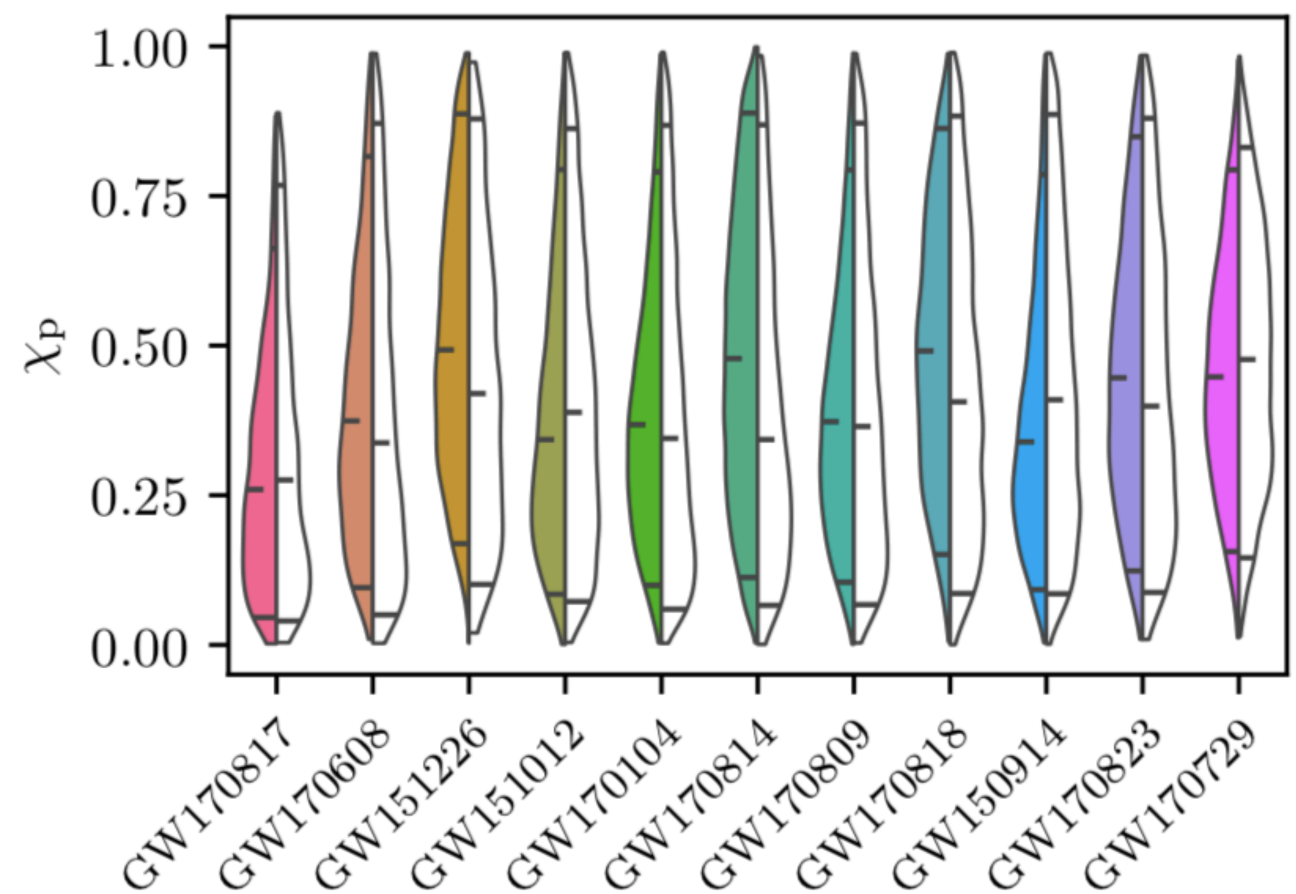
arXiv:1811.12907



All compatible with zero except GW151226 and GW170729

Effective precession spin

arXiv:1811.12907



Rather broad, covering the entire domain from 0 to 1

Spin: preliminary conclusions

- It is not easy to reconstruct the spin direction, especially for what concern the component not aligned with the orbit

- We disfavor scenarios in which most of the black holes merge with large spins aligned with the binary's orbital angular momentum

Merging rate estimation

- Merging rate is a crucial output from population models, but still subjected to large theoretical uncertainty

$$Rate = \frac{\Lambda}{< VT >}$$

Number of astrophysical trigger above a given threshold

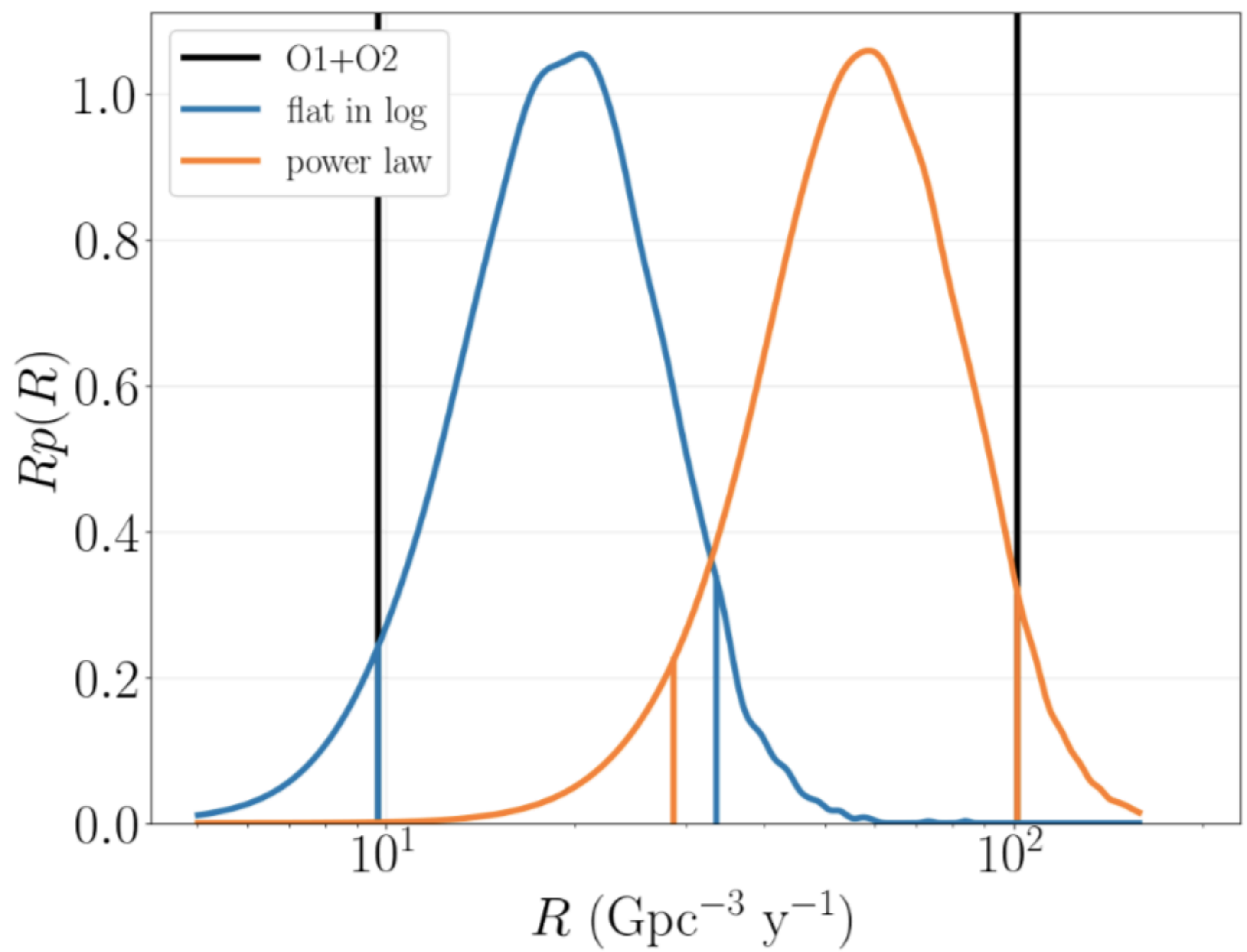
time- and population-averaged space- time volume to which the detector is sensitive

- A rate estimate requires counting the number of signals and then estimating the sensitivity to a population of sources to transform the count into an astrophysical rate
- The inferred rate will depend on the detector sensitivity to the binary population, which strongly depends on masses
  $\rightarrow$ we need to make assumption on mass distribution

BBH merging rate estimation

- Two different mass distribution considered
  - Flat in the log mass
  - Power law (with α = 2.3)

arXiv:1811.12907

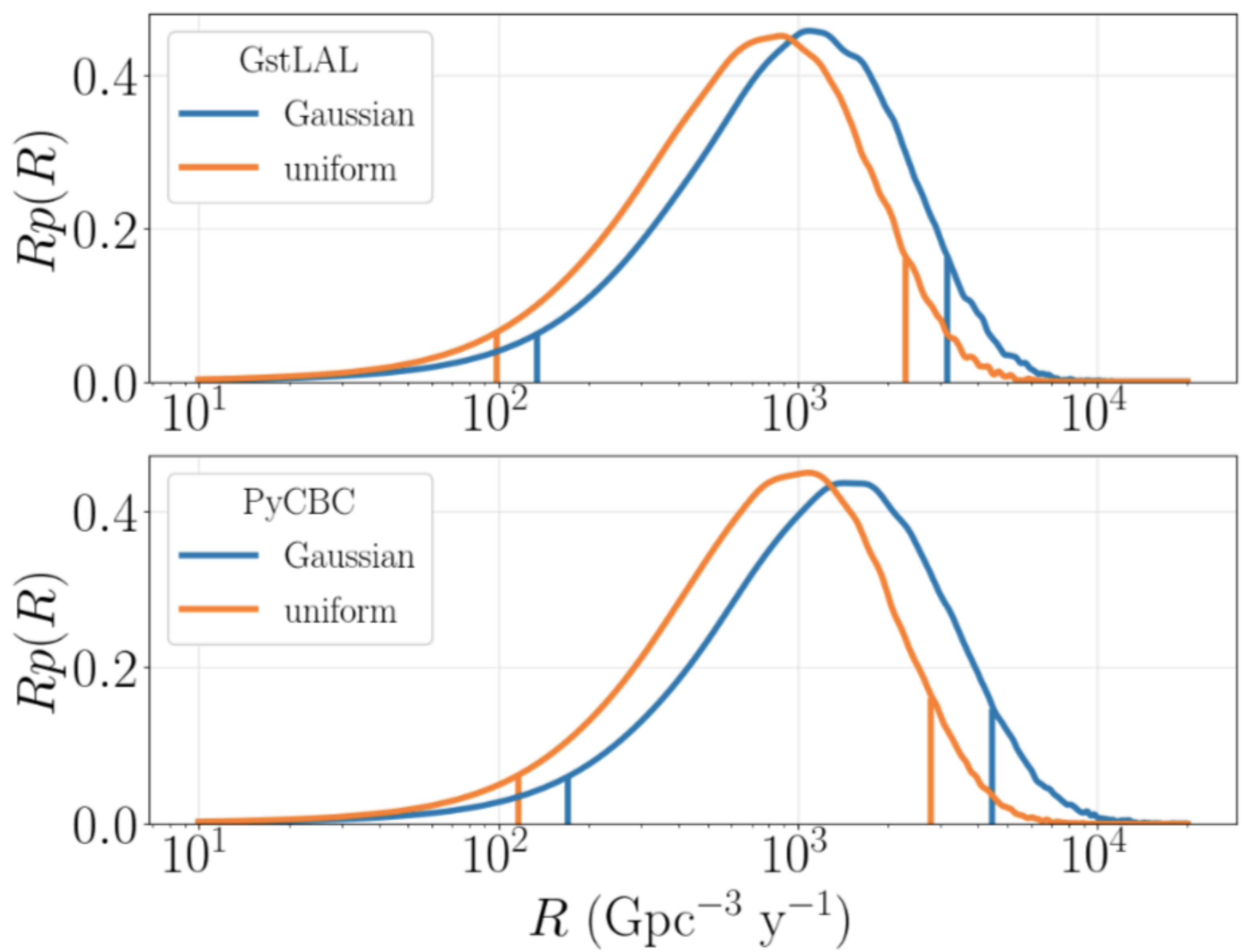


BHH merging rate: [9.5, 99.3] Gpc^{-3}y^{-1}

BNS merging rate estimation

- Two different mass distribution considered
  - Gaussian (with mean =1.33 M⊙ and std 0.09 M⊙)
  - Uniform

arXiv:1811.12907

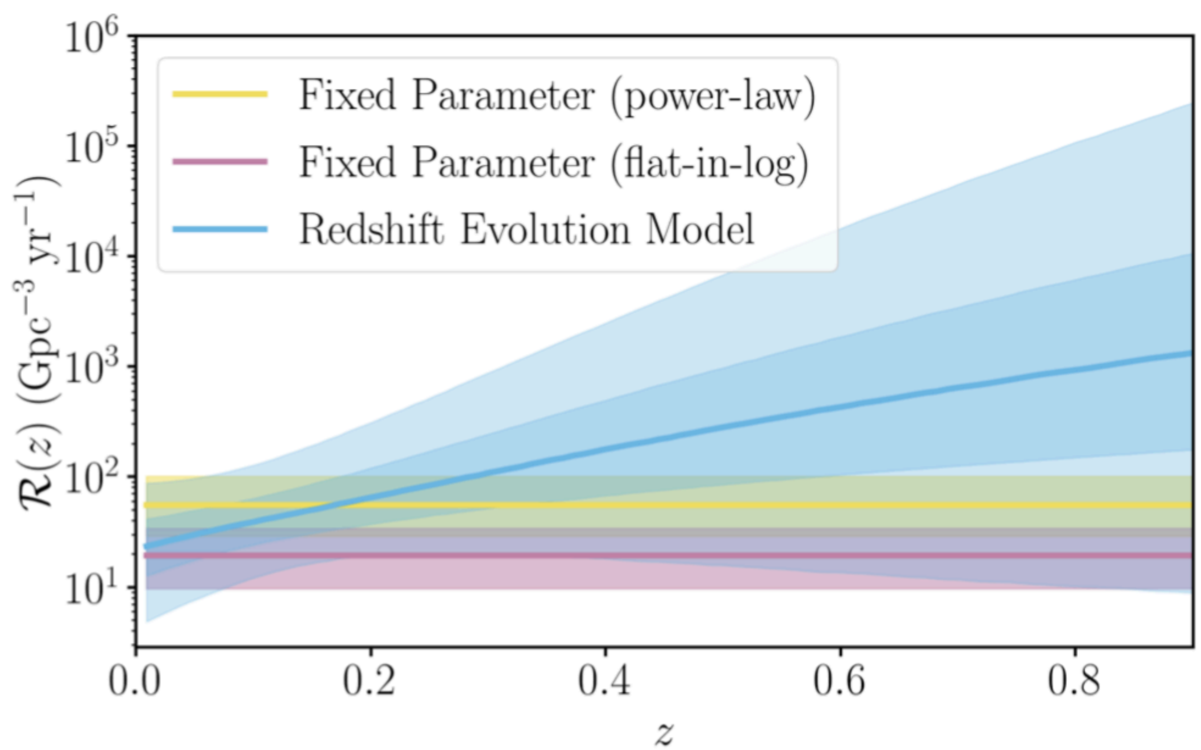


BNS merging rate: [110, 3840] Gpc^{-3}y^{-1}

Evolution of the Merger Rate with Redshift

- Previous estimation done under the assumption of a constant-in-redshift rate density

- Most formation channels predict some evolution of the merger rate with redshift



Binary Black Hole Population Properties Inferred from the First and Second Observing Runs of Advanced LIGO and Advanced Virgo

arXiv:1811.12940

- Constraints on evolution of the BBH merger rate density as a function of redshift show preference for **a merger rate that increases with increasing redshift**

Population properties: perspective

- Hundreds of BBH merger expected in the next years
- Quantitative observation will reduce in the uncertainty of population model parameters (masses, spin, merging rate)

↓

Constraints on the physics of stellar and binary evolution by pairing measured BBH properties with population synthesis models that account for various formation scenarios

NS equation of state from BNS merging

- Unique environment to test extreme high density matter behaviour

- The GW waveform is affected from the components' internal structure as the orbital separation approaches the size of the bodies.

- This effect increases the quadrupole momentum variation, accelerating the merging

NS equation of state from BNS merging

- Each star is characterized by its **deformability**, which, given the equation of state, depends only on its mass.

Constant

$$\Lambda = (2/3)k_2[(c^2/G)(R/m)]^5$$

Second Love number **Radius** **Mass**

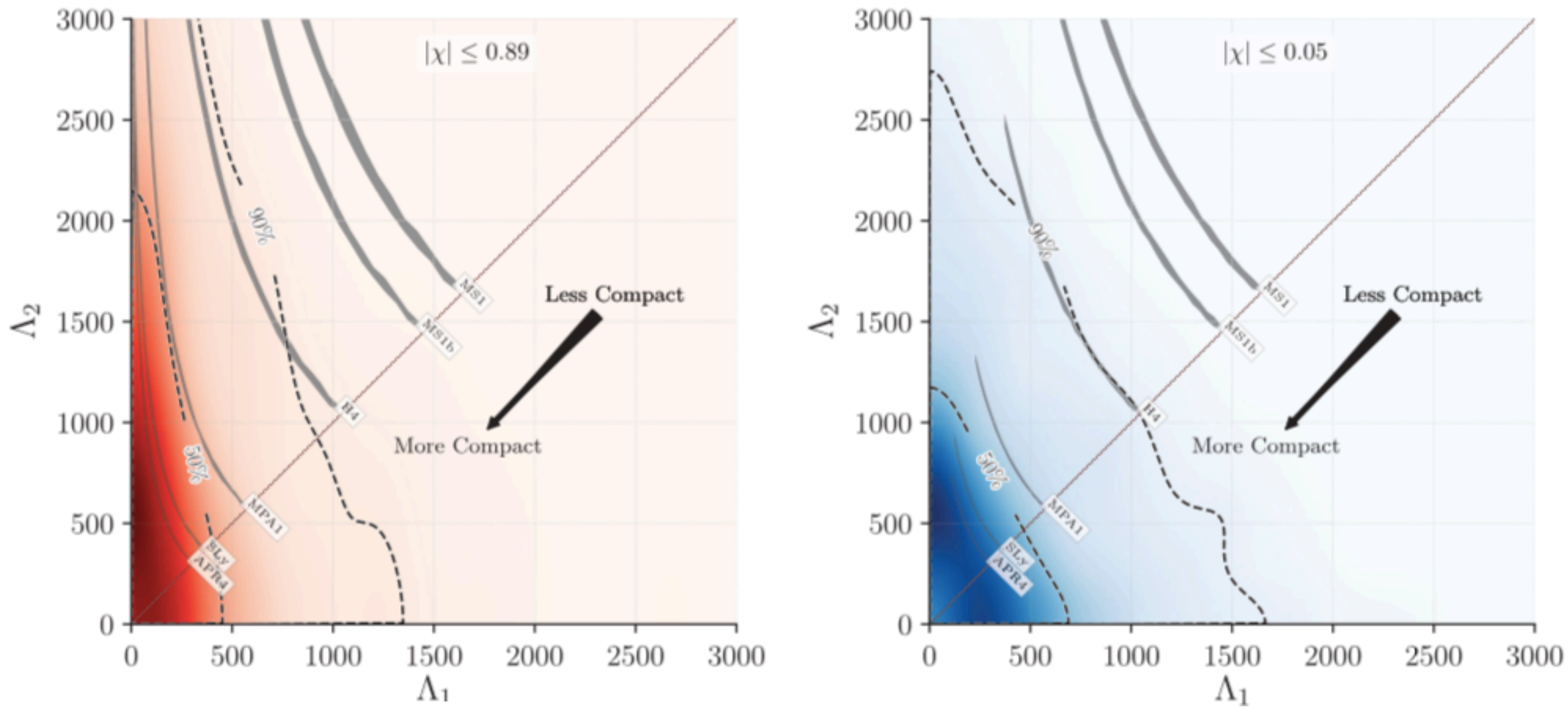
NS equation of state from BNS merging

- The waveform is affected by a combination of the deformability of the two stars

$$\tilde{\Lambda} = \frac{16}{13} \frac{(m_1 + 12 m_2) m_1^4 \Lambda_1 + (m_2 + 12 m_1) m_2^4 \Lambda_2}{(m_1 + m_2)^5}$$

Constrains on the EoS with GW170817

- From GW170817, it has been possible to find constraints on the deformabiliities



Phys. Rev. Lett. **119**, 161101

- We could discard EoS leading to less compact stars, since the corresponding deformabilities fall outside the 90% probability region

Refined analysis on GW170817

- Analysis assumes that both bodies have the same equation of state and have spins within the range observed in Galactic binary neutron stars.

PHYSICAL REVIEW LETTERS **121,** 161101 (2018)

GW170817: Measurements of Neutron Star Radii and Equation of State

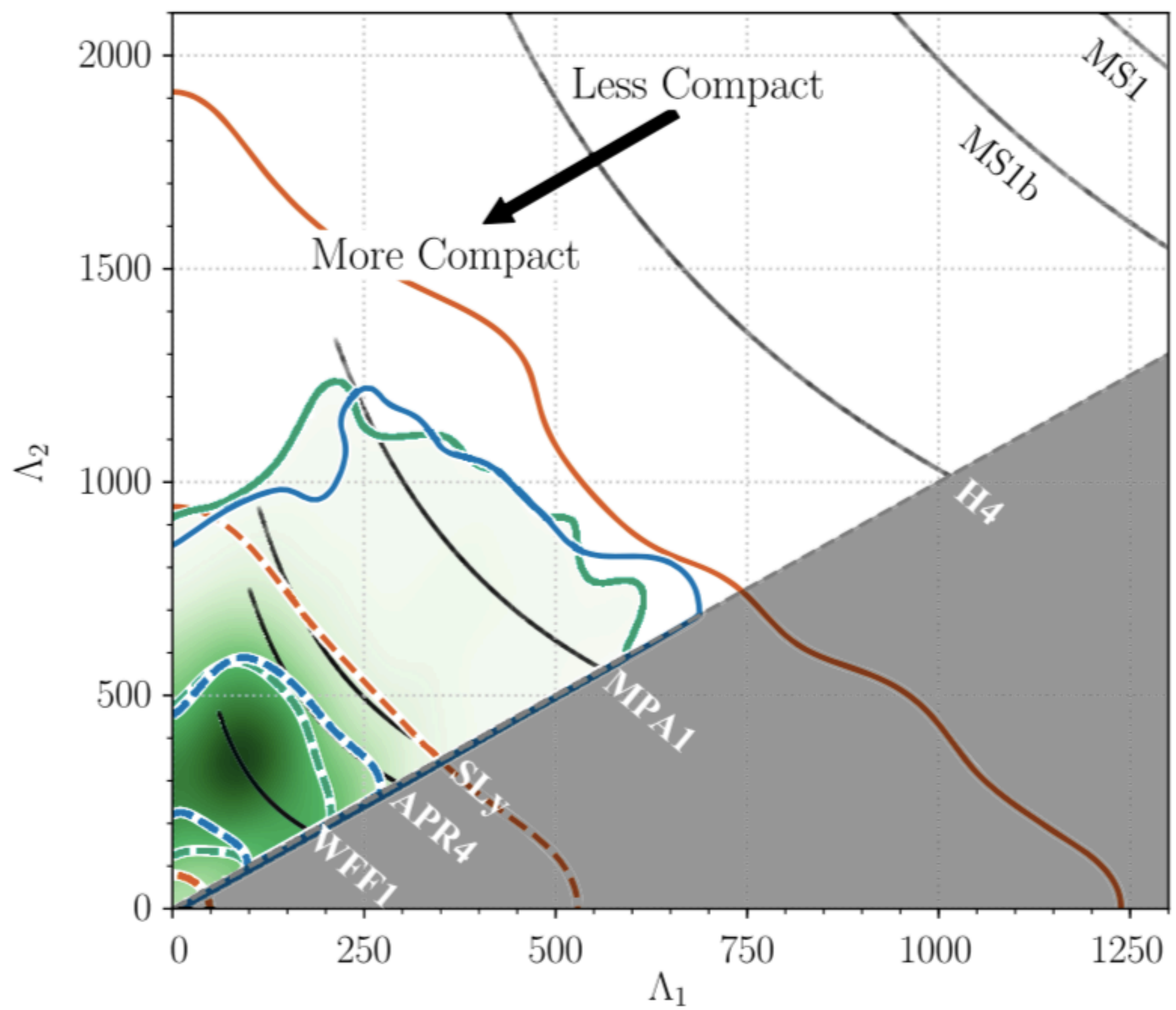
B. P. Abbott *et al.*[*]
(The LIGO Scientific Collaboration and the Virgo Collaboration)

(Received 5 June 2018; revised manuscript received 25 July 2018; published 15 October 2018)

- two methods used:
  - Use of relations insensitive to EoS between various macroscopic properties of the neutron stars
  - Use of an efficient parametrization of the defining function p(ρ) of the equation of state itself

Refined analysis on GW170817

Tidal deformabilities of the two binary components

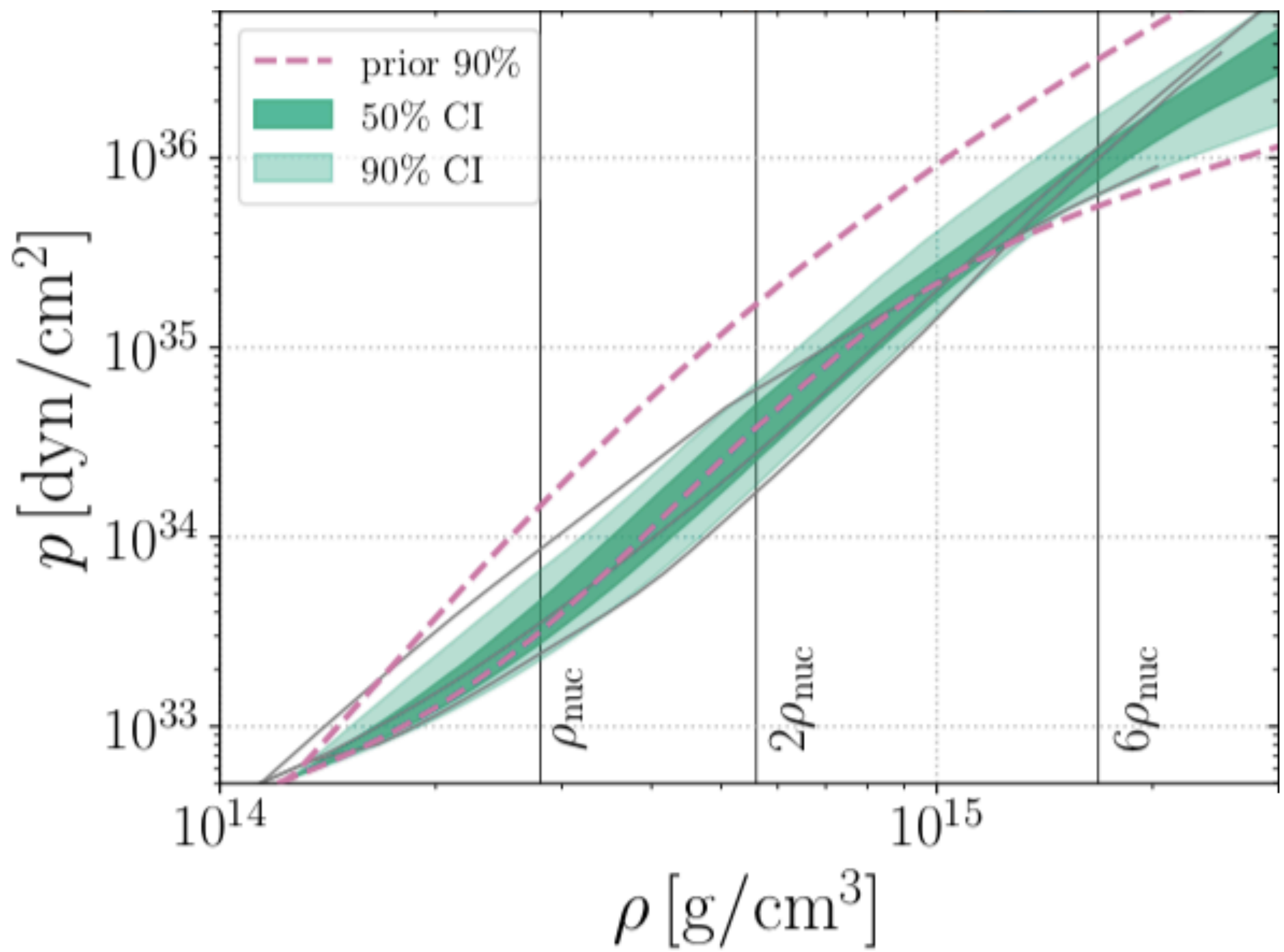


Phys. Rev. Lett. **121**, 161101 (2018)

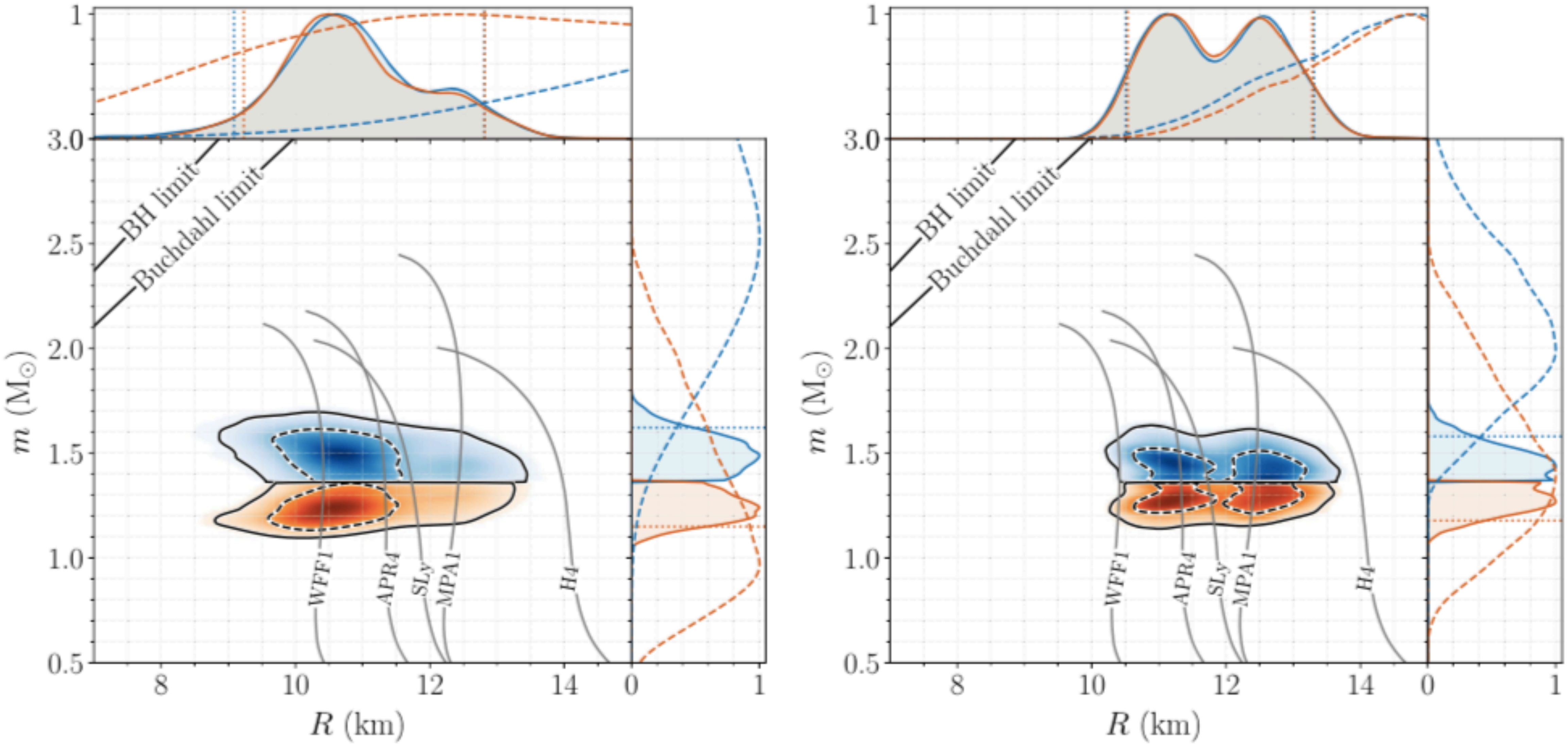
Green = EoS independent relation
Blue = a parametrized EOS without a maximum mass requirement
Orange = independent EOSs

Pressure as a function of the restmass density of the NS interior

Phys. Rev. Lett. **121**, 161101 (2018)



Mass and areal radius of each binary component



- Using EOS-insensitive relations

- Using parametrized EOS with lower limit on the max mass 1.97 M⊙

Perspectives

- More observation expected in the next runs with increased SNR will reduce statistical uncertainty

Epoch		2015 – 2016	2016 – 2017	2018 – 2019	2020+	2024+
Planned run duration		4 months	9 months	12 months	(per year)	(per year)
Expected BNS range/Mpc	LIGO	40 – 80	80 – 120	120 – 170	190	190
	Virgo	—	20 – 65	65 – 85	65 – 115	125
	KAGRA	—	—	—	—	140
Achieved BNS range/Mpc	LIGO	60 – 80	60 – 100	—	—	—
	Virgo	—	25 – 30	—	—	—
	KAGRA	—	—	—	—	—
Estimated BNS detections		0.05 – 1	0.2 – 4.5	1 – 50	4 – 80	11 – 180
Actual BNS detections		0	1	—	—	—

arXiv:1304.0670

- Necessity for improving waveform models and data analysis techniques to reduce systematic uncertainties

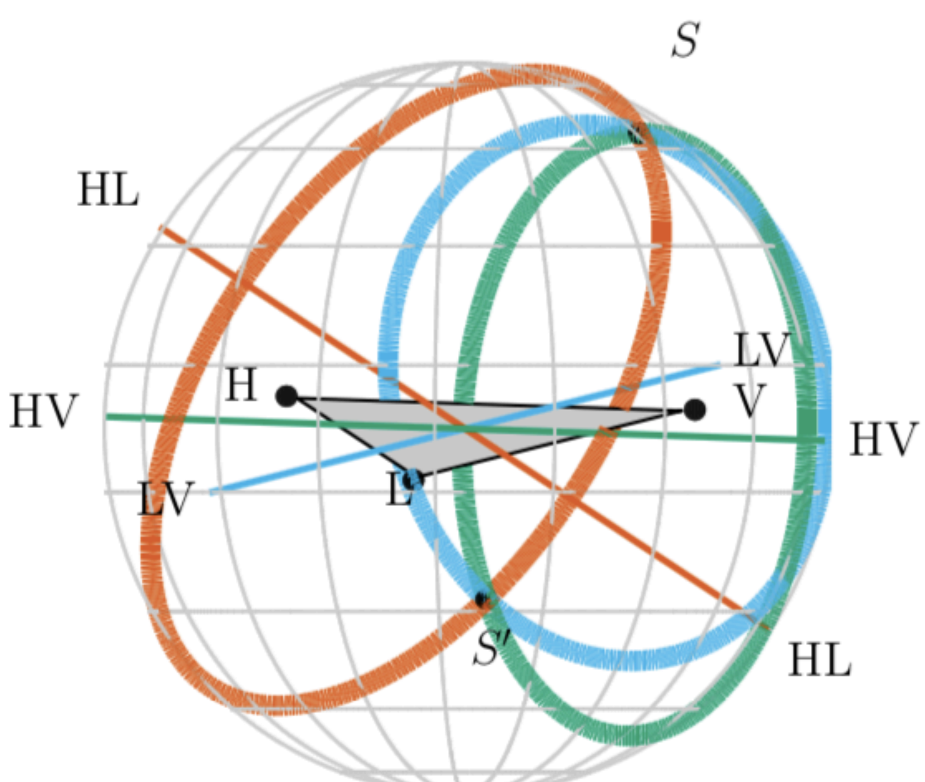
Localization

Precise localization of compact binary mergers (sky location and distance) has two major payoffs:

- It allows for an effective EM follow up to detect associated phenomena
- It can be used to measure Hubble constraint

Sky location

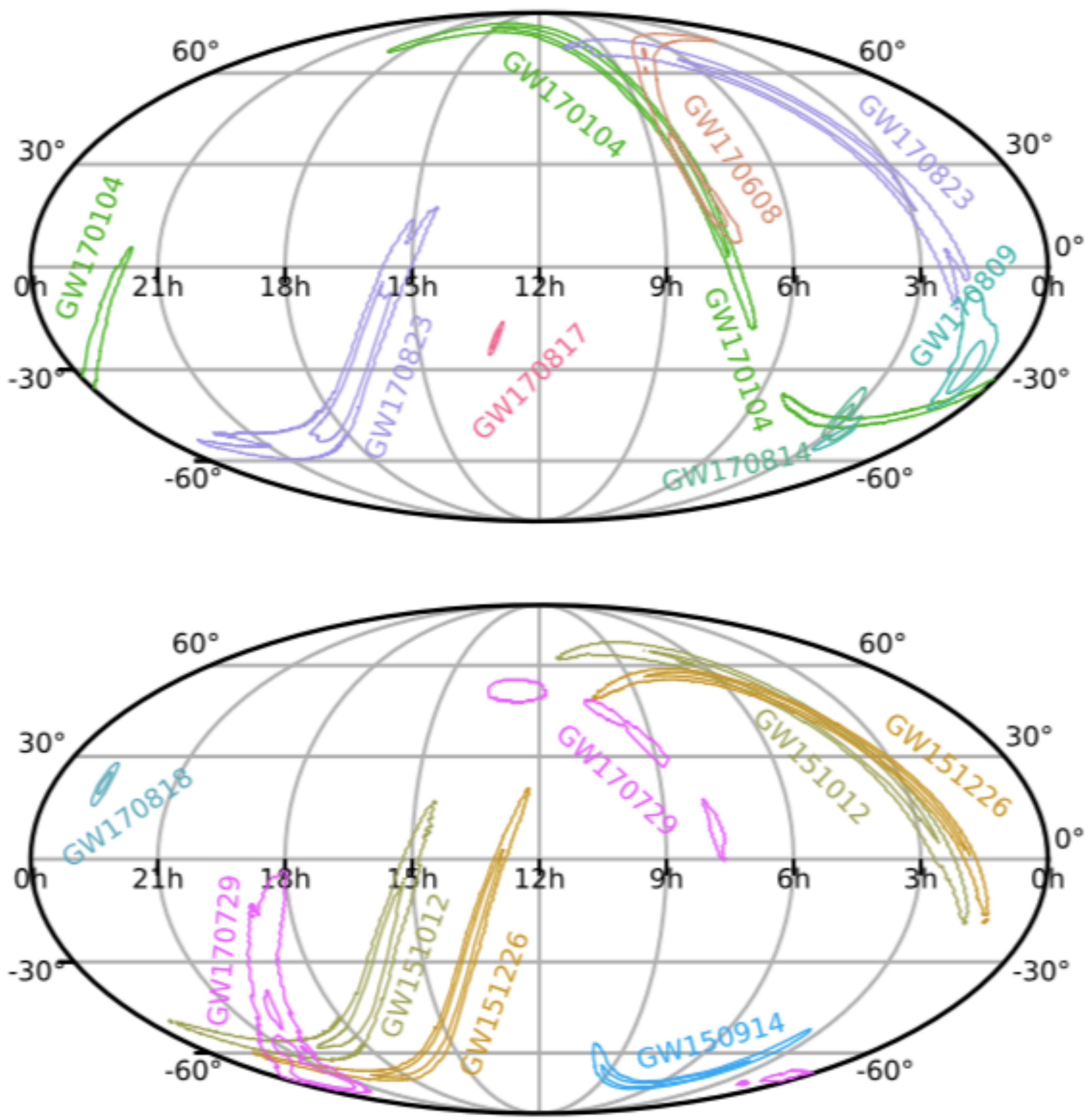
- Triangulation performed using time delays at the different site
- Additional information such as signal amplitude and phase, and precession effects can further constrain the area



arXiv:1304.0670

- 2 detector → 100 -1000 deg^2
- 3 detector → 10 - 100 deg^2
- 4 detector → $<$ 10 deg^2

Sky location



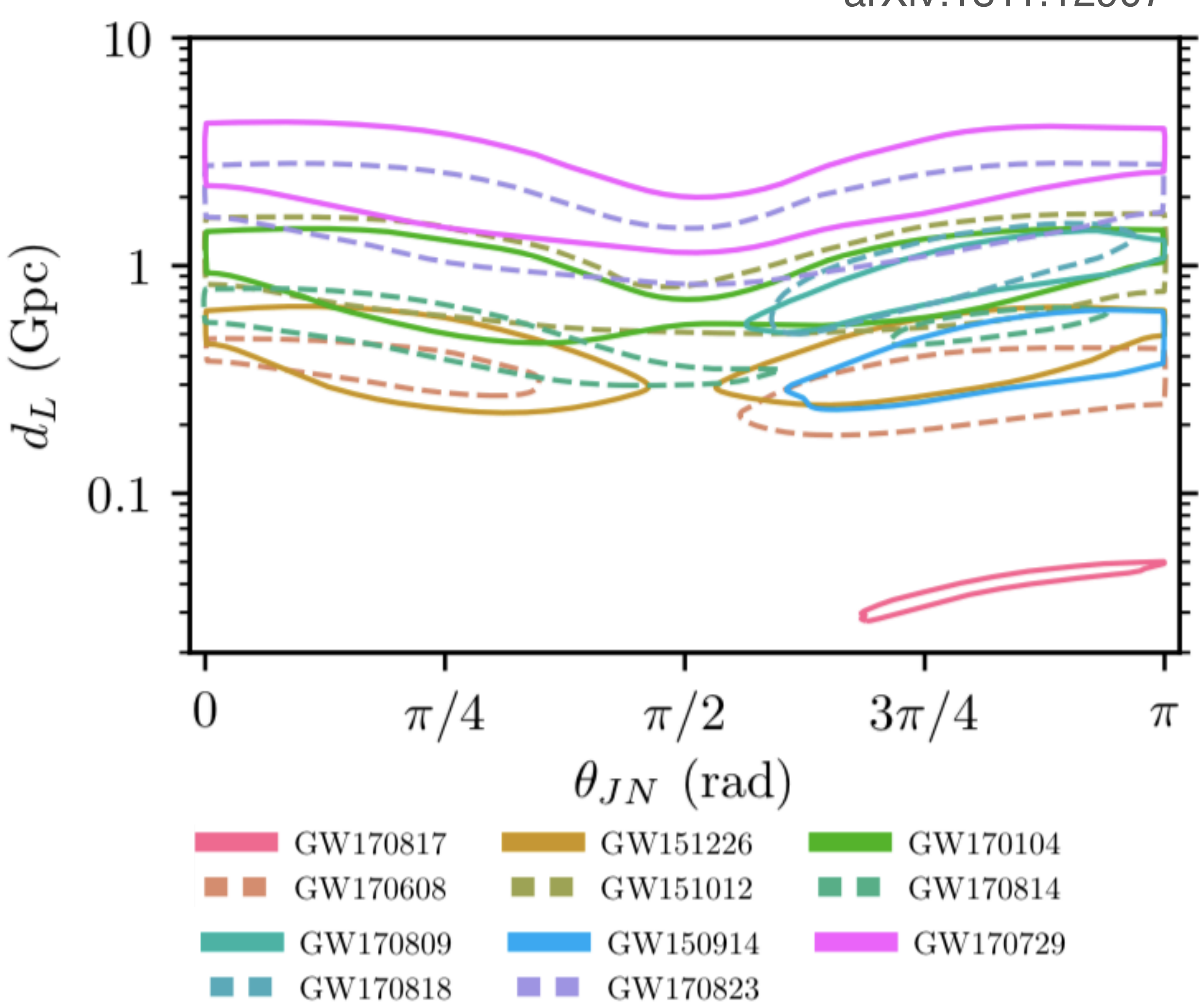
Event	$\Delta\Omega/\mathrm{deg}^2$
GW150914	179
GW151012	1476
GW151226	1033
GW170104	924
GW170608	396
GW170729	1069
GW170809	340
GW170814	87
GW170817	16
GW170818	39
GW170823	1628

arXiv:1811.12907

Distance

- Waveform amplitude proportional to luminosity distance
- Uncertainty in distance measurement is dominated by the degeneracy with the binary's inclination, which also determines the signal amplitude
- The degeneracy could be broken by observing with more non co-aligned detectors

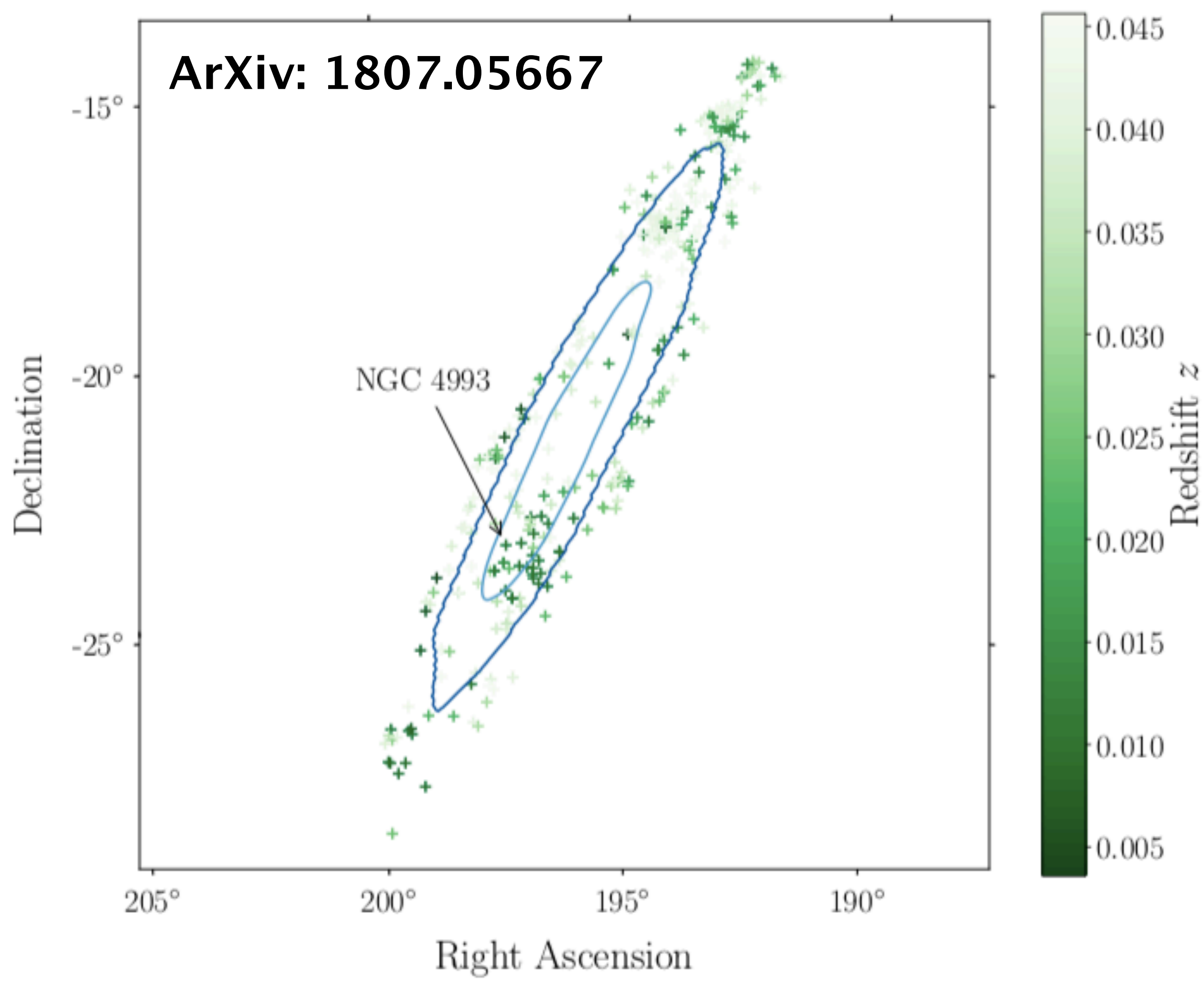
arXiv:1811.12907



Event	D_L/Mpc	z
GW150914	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$
GW151012	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$
GW151226	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$
GW170104	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$
GW170608	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$
GW170729	2760^{+1290}_{-1350}	$0.48^{+0.18}_{-0.21}$
GW170809	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$
GW170814	560^{+140}_{-210}	$0.12^{+0.03}_{-0.04}$
GW170817	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$
GW170818	1020^{+430}_{-360}	$0.20^{+0.07}_{-0.07}$
GW170823	1860^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$

Detection of electromagnetic counterpart

- Distance information can further aid the hunt for counterparts, particularly if the the localization can be used together with galaxy catalogs

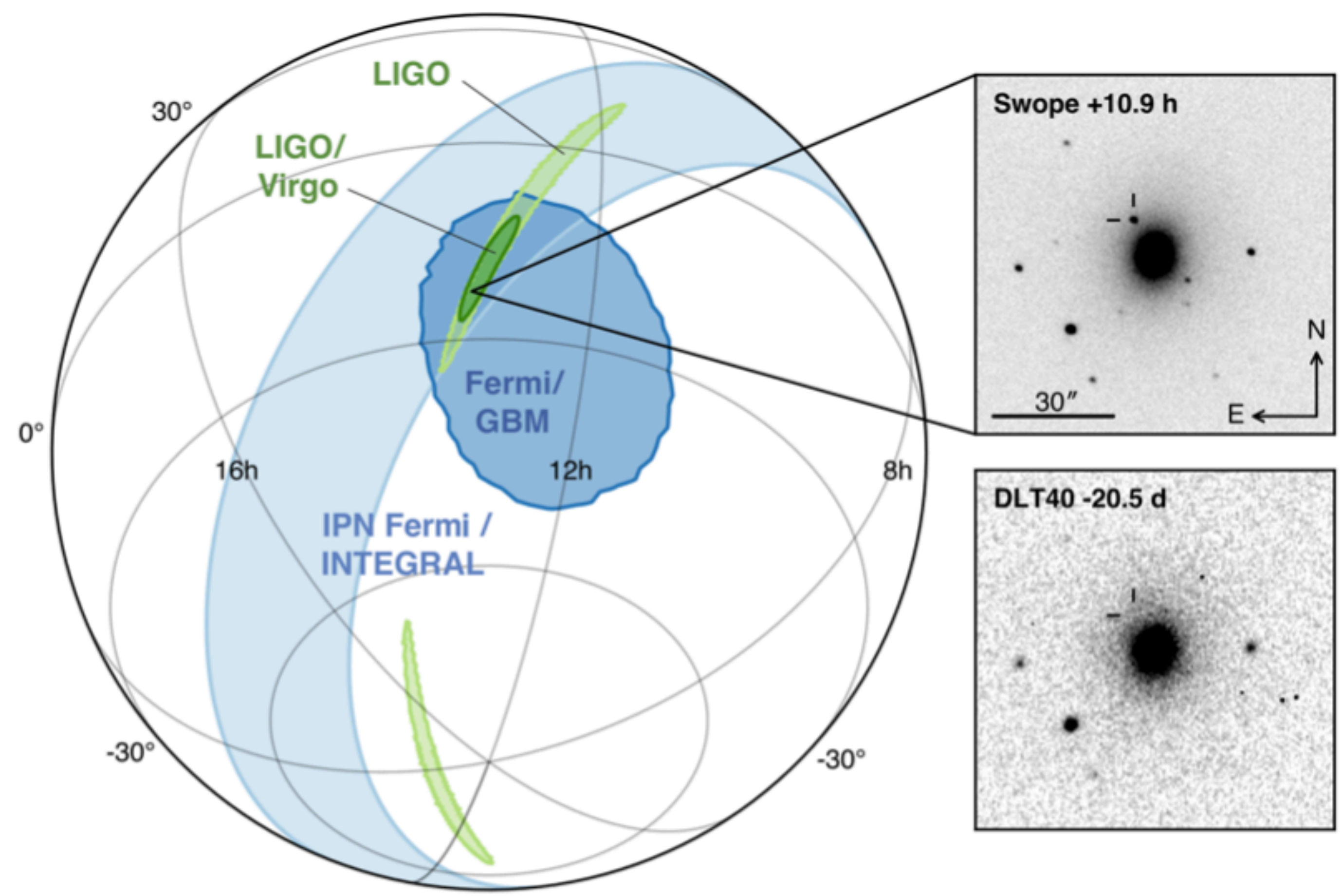


Localization of BNS merger GW170817

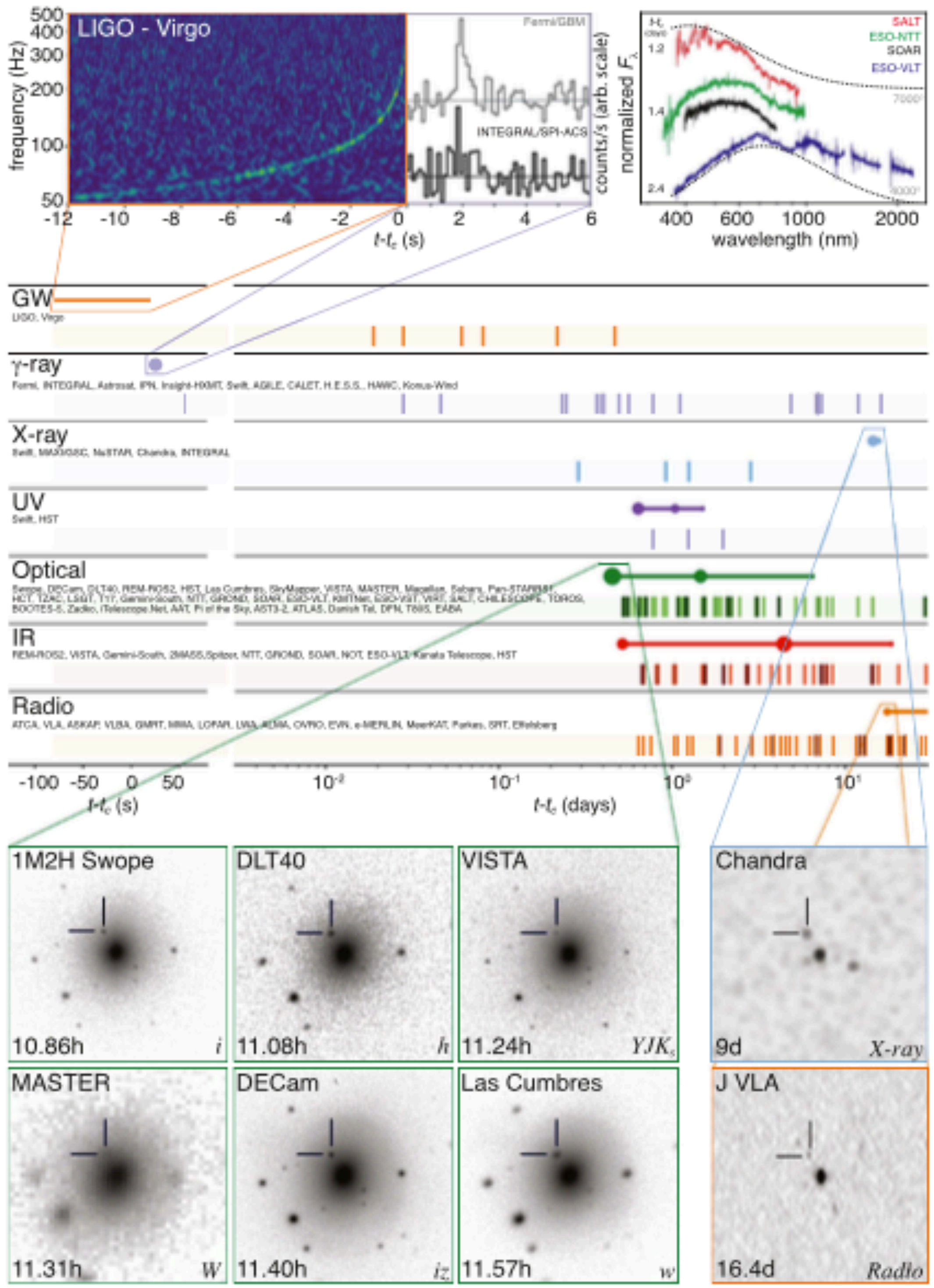
- Sky location area 31 deg
- Distance of 40 ± 8 Mpc

Electromagnetic counterpart of GW17017

- Thanks to the localization provided by GW, EM counterpart of the BNS merger has been detected



The beginning of multimessanger astronomy



Multi-messenger Observations of a Binary Neutron Star Merger
The Astrophysical Journal Letters, Volume 848, Number 2

- Short GRB associated with BNS merger
- Observation of the **kilonova**: an electromagnetic radiation due to the radioactive decay of heavy r-process nuclei

Cosmology with gravitational waves

- Independent estimation of Hubble constant
- Search for stochastic background

The Hubble constant

- The Hubble constant measures the mean expansion rate of the Universe

$$V_H = H_0 \cdot d$$

Source velocity **Source distance**

Previous estimations

- Standard candles
- *Planck* measurements of the cosmic microwave background anisotropies

show some discrepancy

Estimation of Hubble constant with GW

- The amplitude of GW is proportional to their distance: they can be used as **standard sirens**

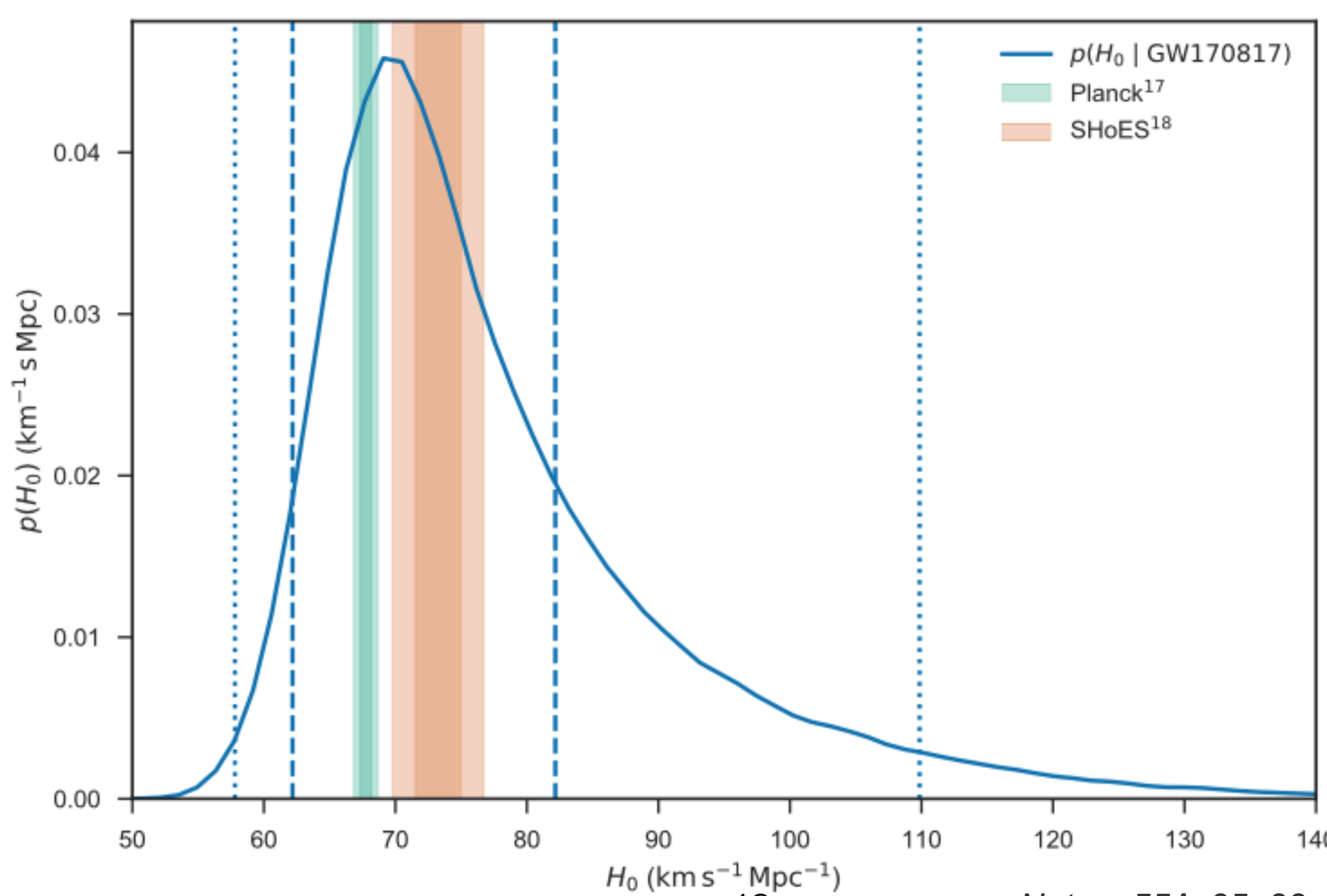
- It can provide a completely independent measurement

- But how to estimate the redshift?

Estimation of Hubble constant with GW

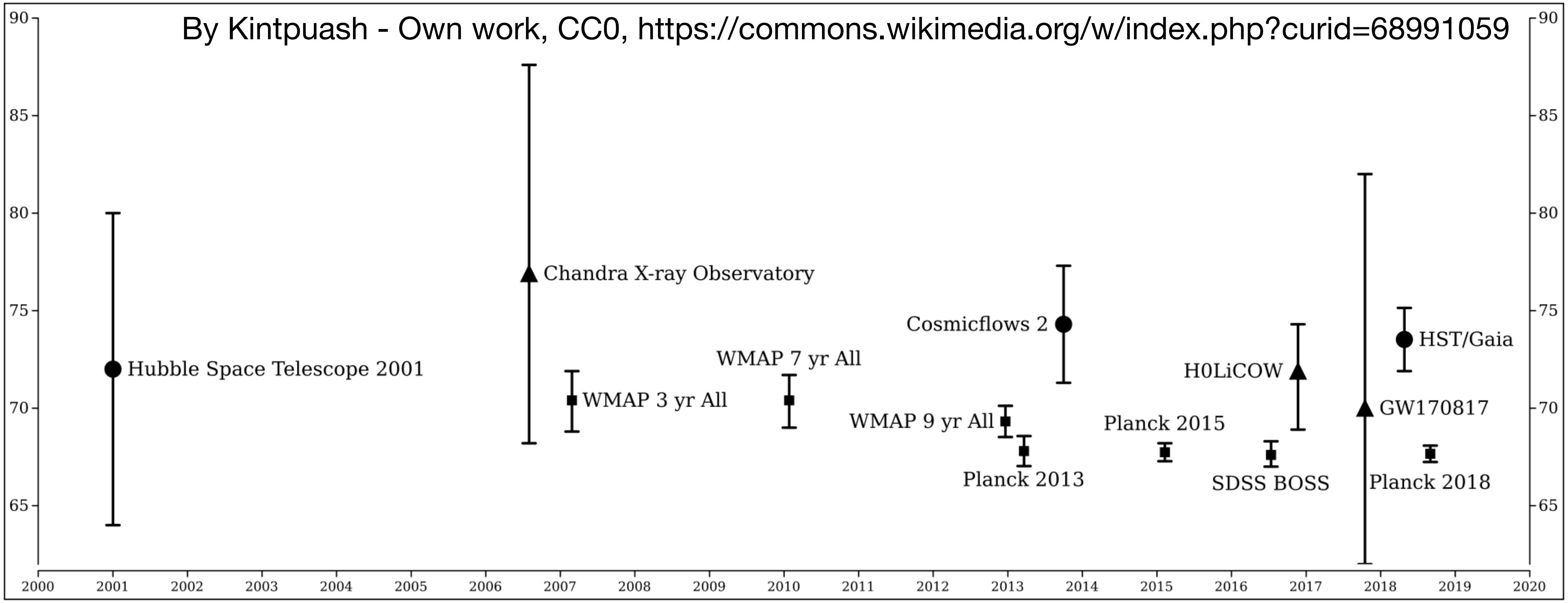
- Detection of an EM counterpart can locate the galaxy and provide the redshift
- It has been done with GW170817

$$H_0 = 70^{+12}_{-8} \mathrm{km\,s^{-1} Mpc^{-1}}$$



Nature **551**, 85–88

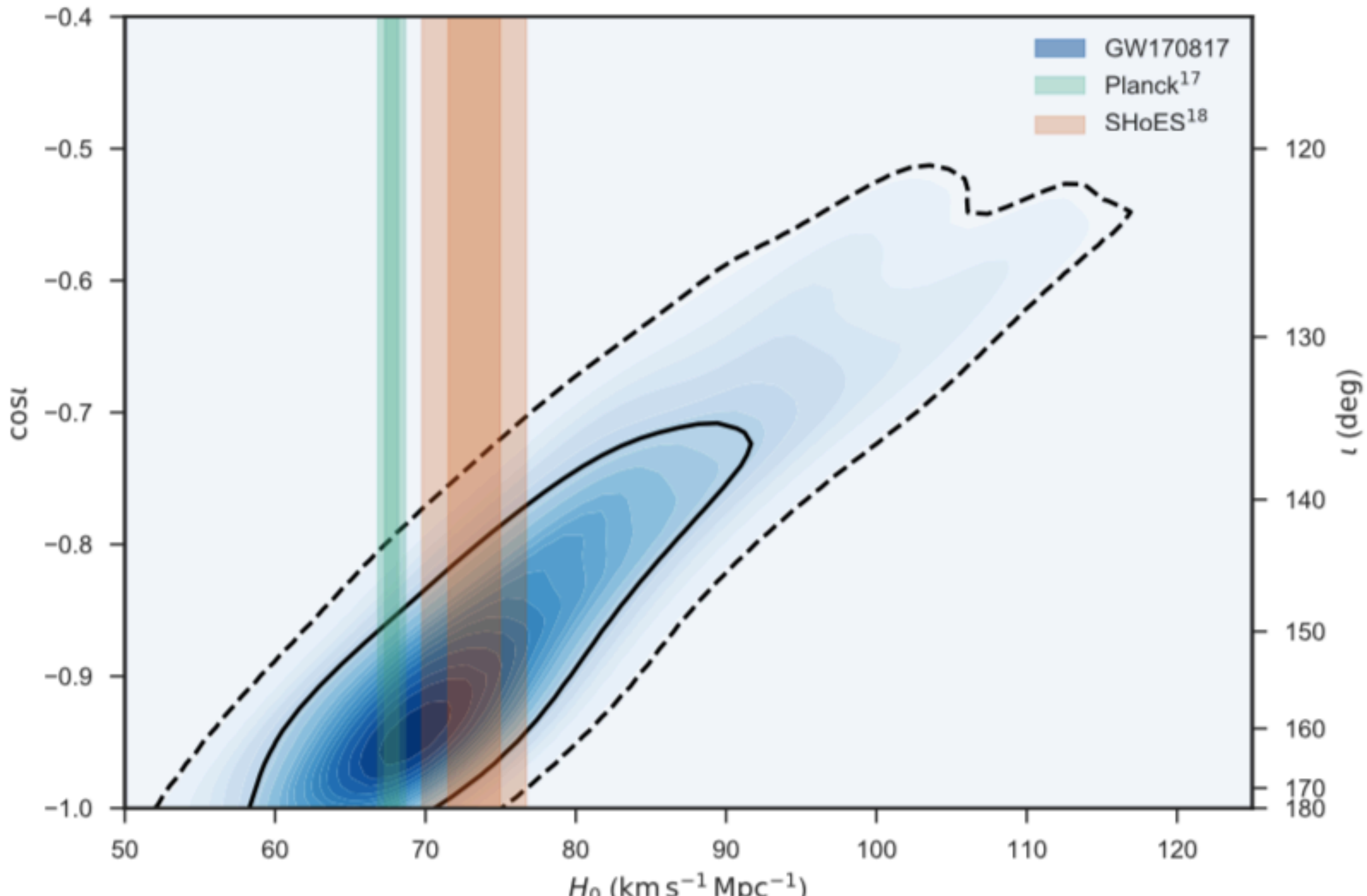
Estimation of Hubble constant from 2011



- ● Circles represent calibrated distance ladder measurements
- ■ Squares represent early universe CMB/BAO measurements
- ▲ Triangles are independent measurements

How to improve the precision?

- Main source of uncertainty is due to the degeneracy between distance and inclination



Nature **551**, 85–88

- Better constrain on the polarization provided by non aligned detectors (as KAGRA and Virgo)

Other way to obtain the redshift

- By using statistical approach on many observations, using error regions on the sky to limit the possible number of host galaxies

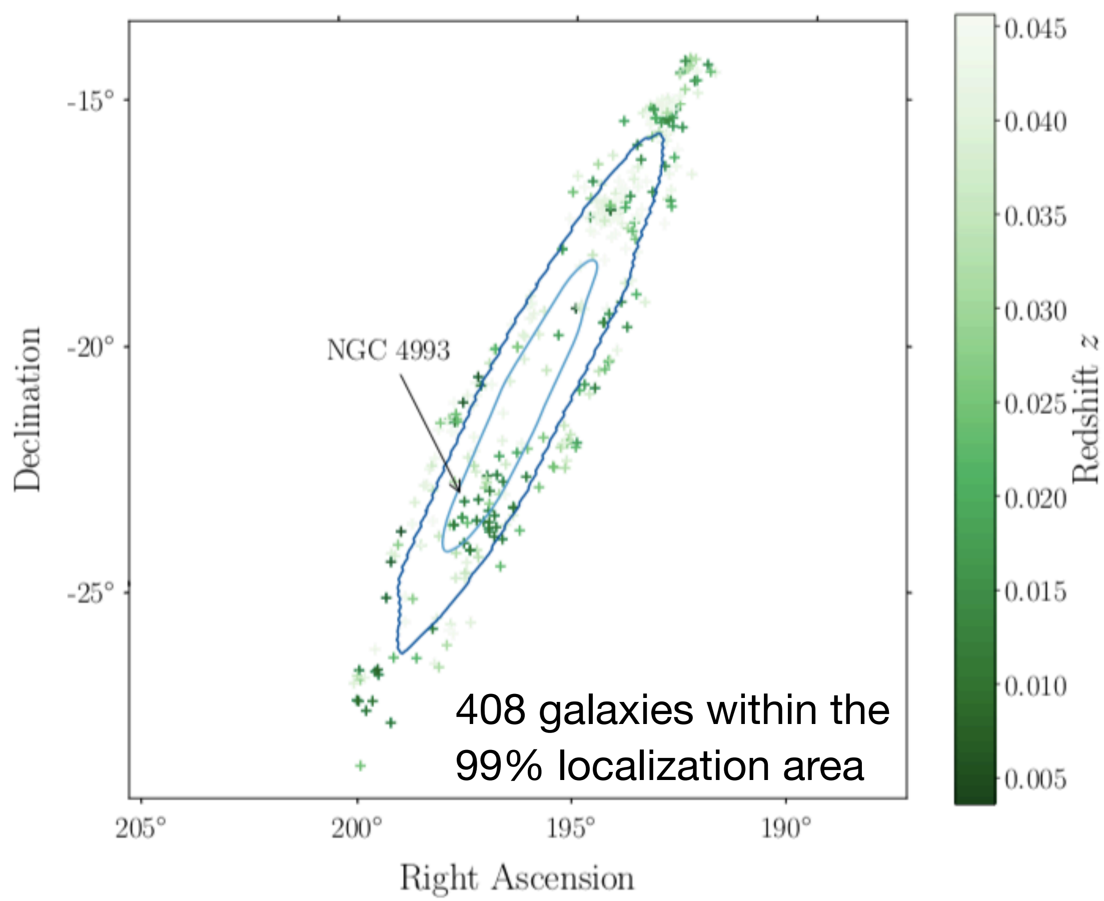
- By measuring tidal effects in binary NS-NS or BH-NS merger which depends on the rest-frame mass (assuming to know the EoS)

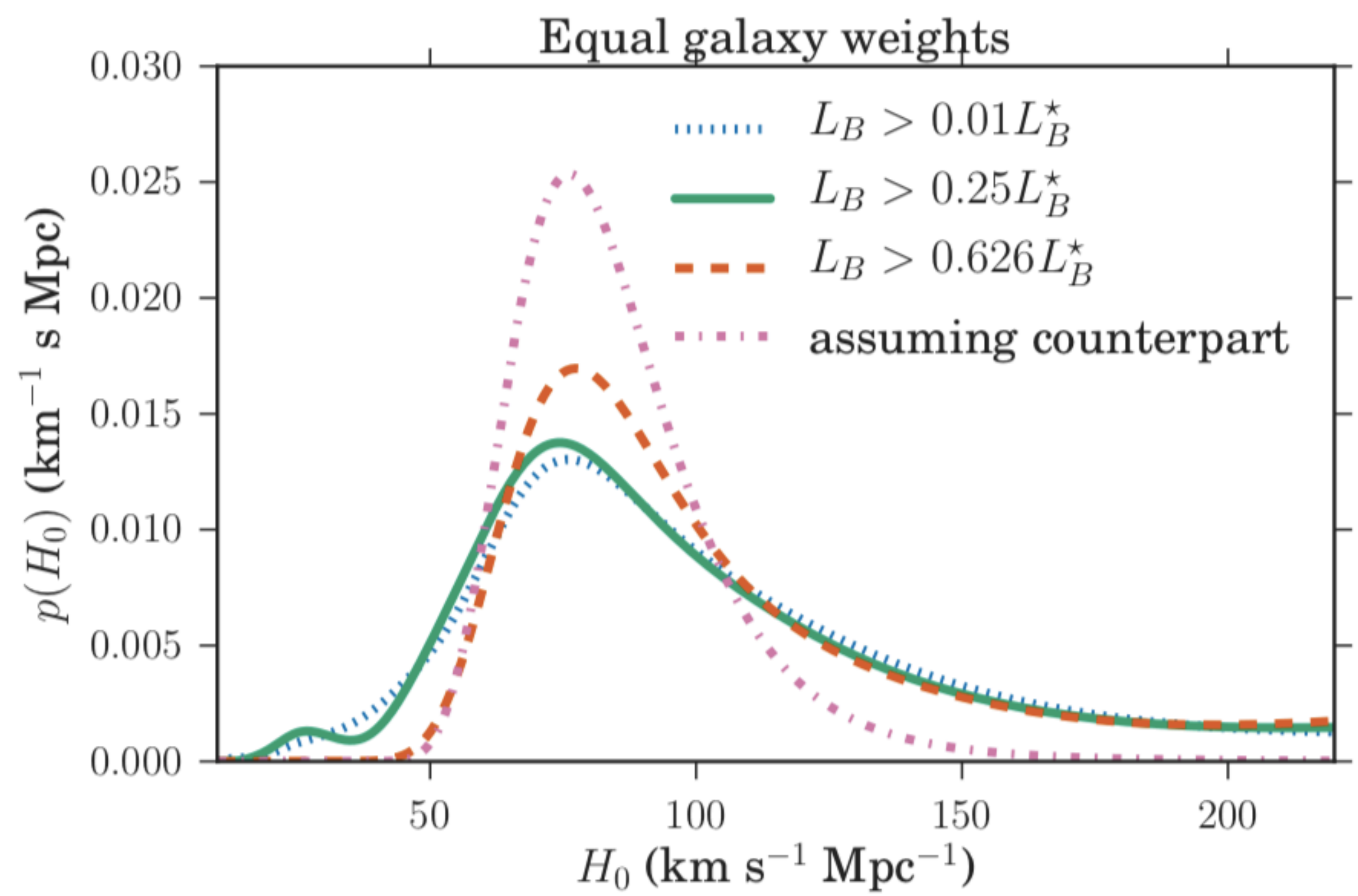
- By using information encoded in the postmerger signal which frequency depending of the rest-frame mass of the sources

- By exploiting the narrowness of the mass distribution of the neutron star population.

Redshift from galaxy statistics without EM counterpart

- Can be used also for BBH merger
- It has been successfully tested test with GW170817



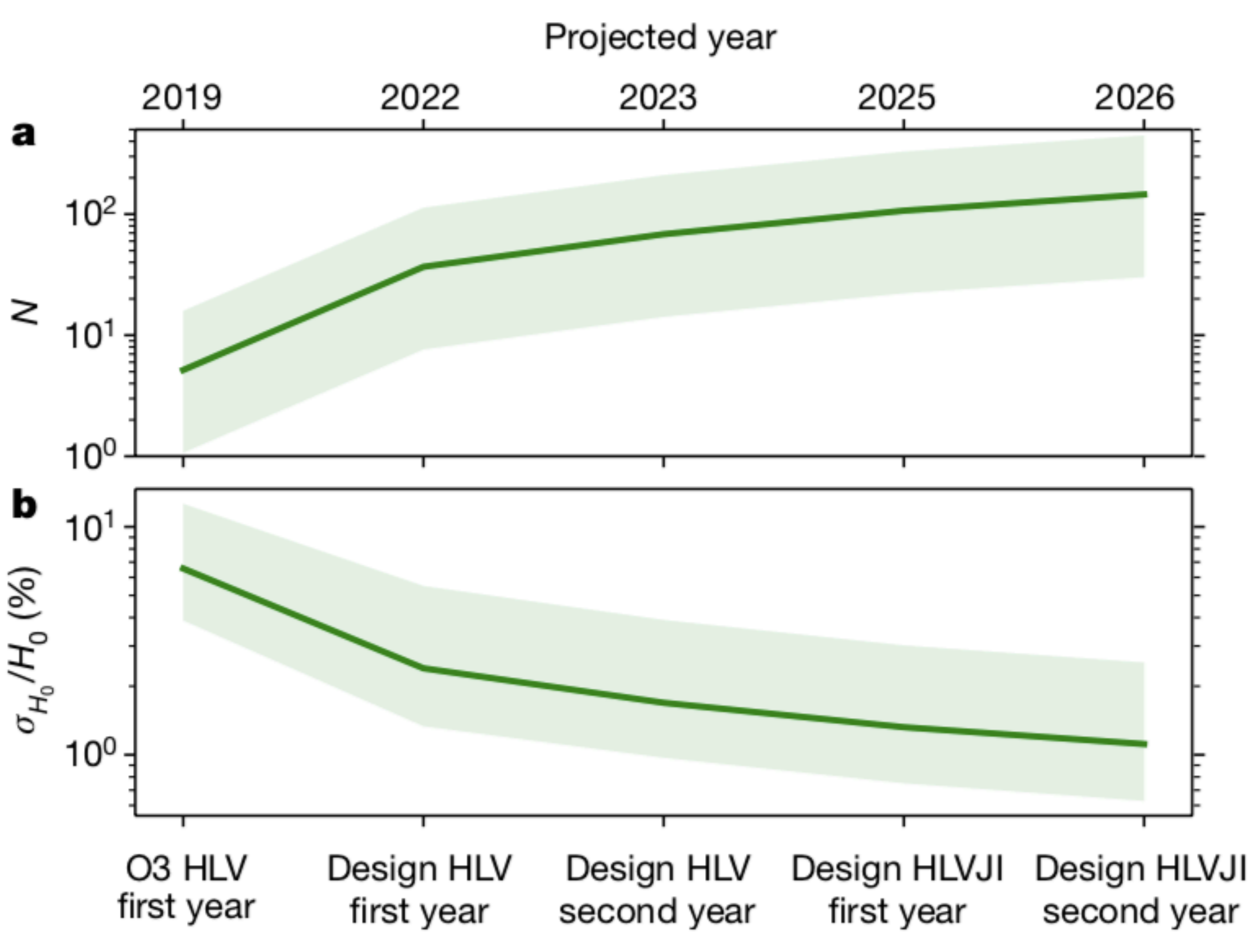


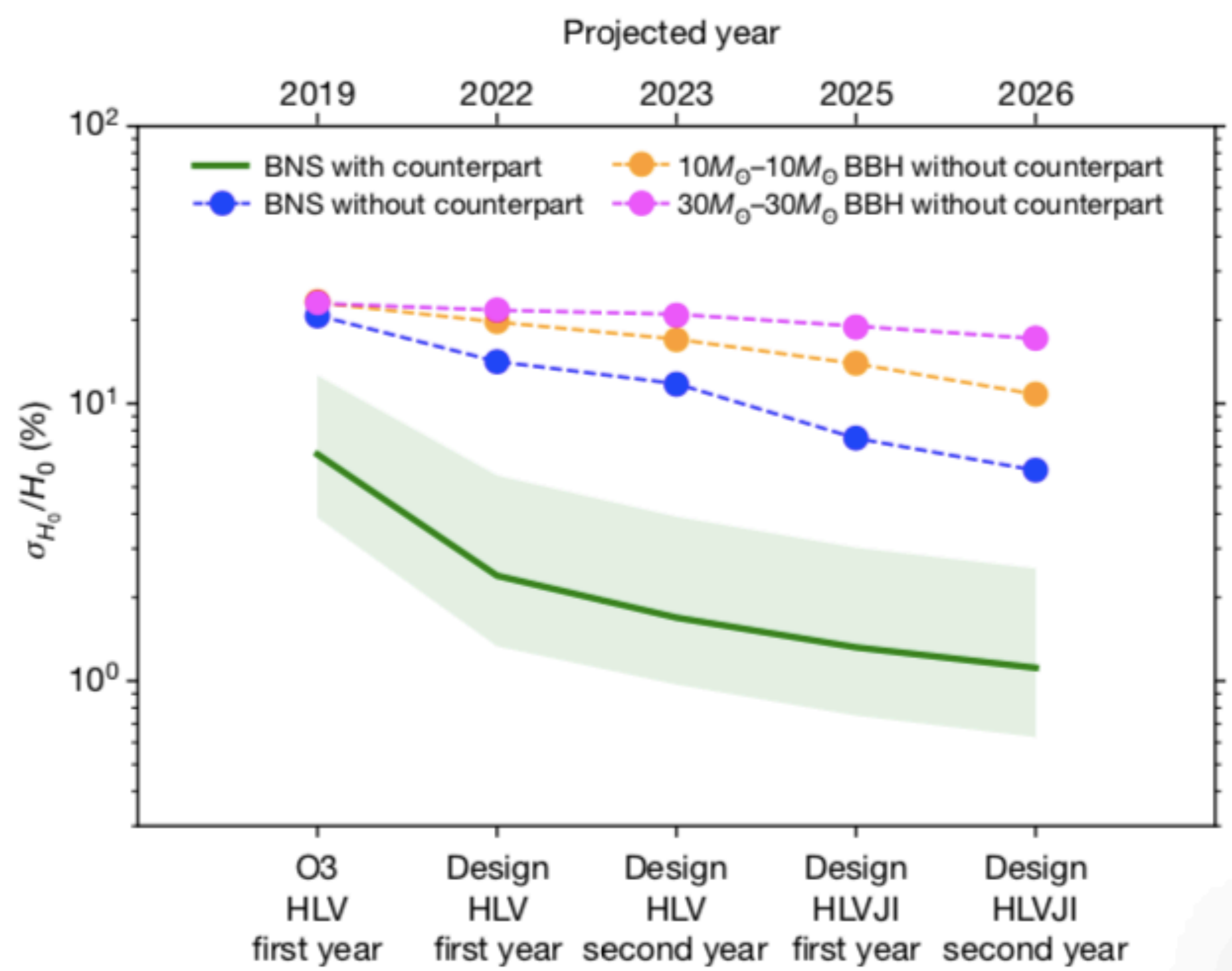
A standard siren measurement of the Hubble constant from GW170817 without the electromagnetic counterpart
ArXiv: 1807.05667

$$H_0 = 76^{+48}_{-23}\,\mathrm{km\,s^{-1}Mpc^{-1}}$$

Perspective

- The precision on H0 estimate is expected to decrease to few percents in the coming years





A two per cent Hubble constant measurement from standard sirens within five years

Hsin-Yu Chen[1,2*], Maya Fishbach[2] & Daniel E. Holz[2,3,4]

25 OCTOBER 2018 | VOL 562 | NATURE | 545

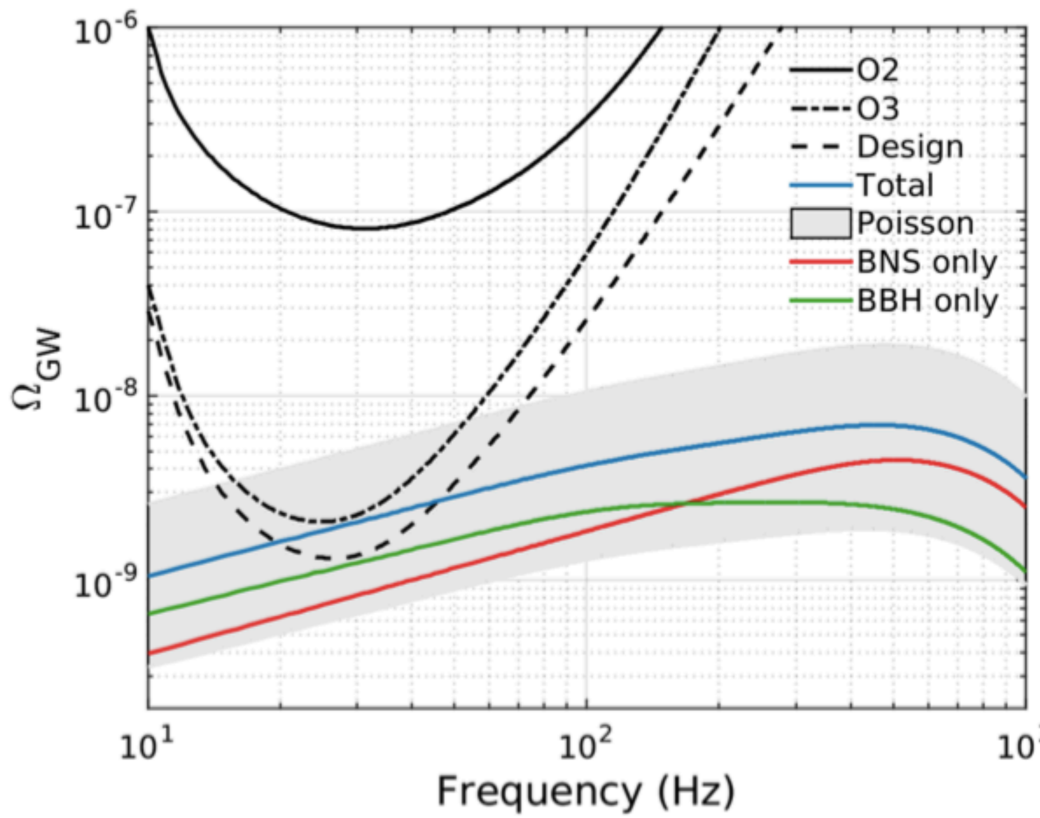
Stochastic background

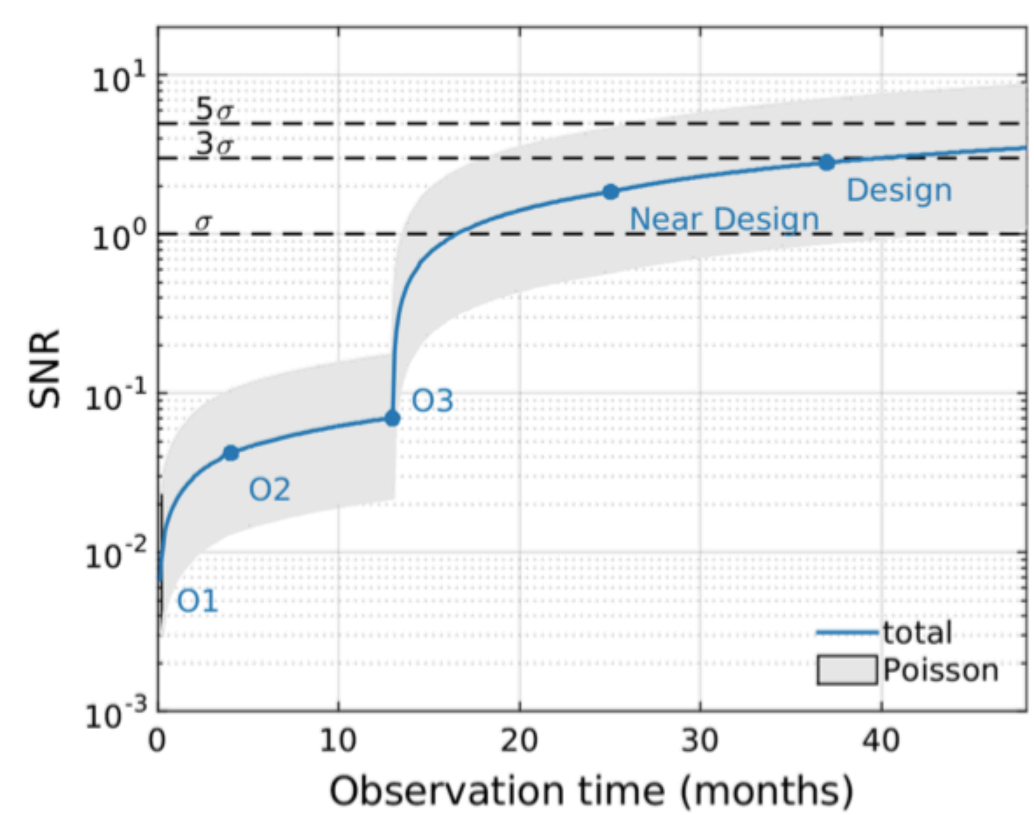
- Random GW signal produced by the superposition of many weak, independent, unresolved sources
    - Astrophysical: unresolved compact binary coalescence, pulsar, supernovae..
    - Cosmological: stochastic processes in the early Universe

Astrophysical stochastic background

- Detectable from noise by cross-correlating the data streams from two or more detectors

- Estimation from updated merging rate: **probably it can be observed in O3**





PHYSICAL REVIEW LETTERS **120,** 091101 (2018)

GW170817: Implications for the Stochastic Gravitational-Wave Background from Compact Binary Coalescences

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

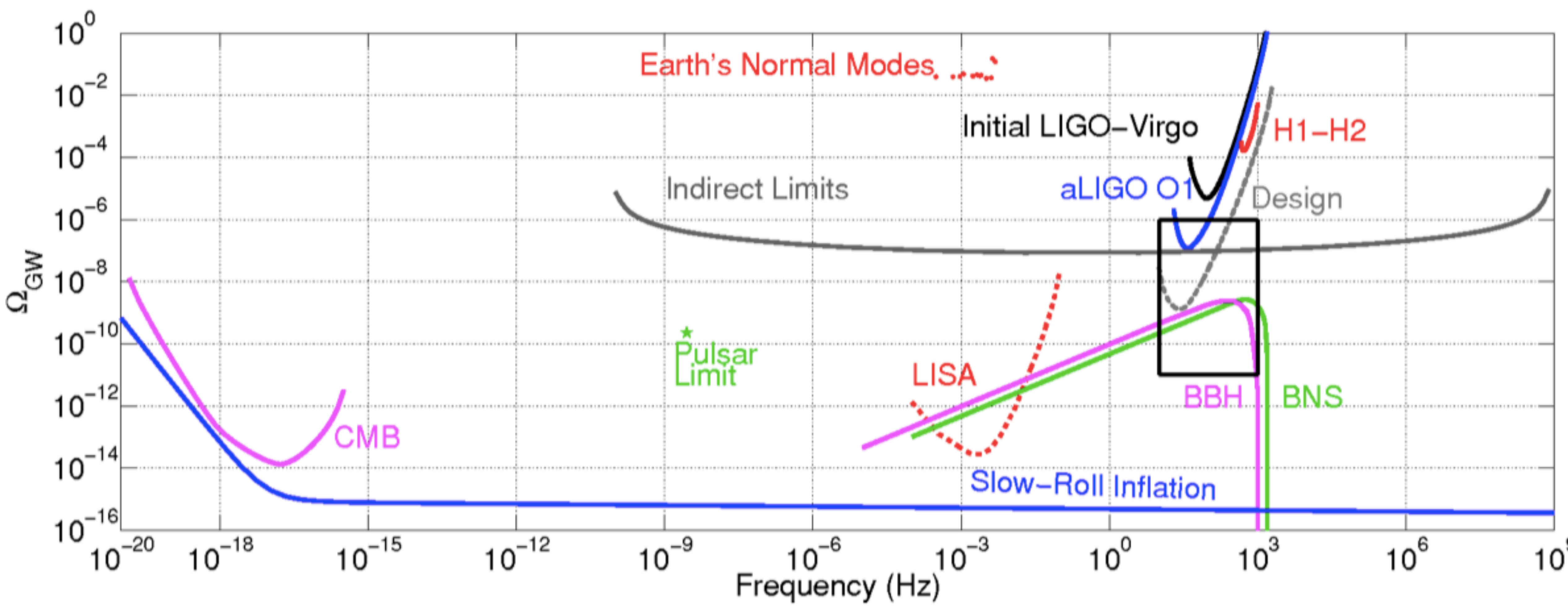
Astrophysical stochastic background

Scientific interests:

- Investigate the composition: possibility to distinguish BBH and BNS background from time-domain structures
- Stochastic analysis to check isotropy, polarization, consistency with general relativity
- Understanding it to subtract it and enable searches for a background of cosmological origin

Cosmological stochastic background

- GW analogous of cosmic microwave background
- Originated by different process in the early universe (i.e quantum fluctuation during the inflation)
- Probably too weak for 2nd generation detectors



Upper Limits on the Stochastic Gravitational-Wave Background from Advanced LIGO's First Observing Run

B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration)
Phys. Rev. Lett. **118**, 121101 – Published 24 March 2017

Conclusions

- Clear scientific goals for 2nd generation GW detector network
- Proof of principle and promising preliminary results already obtained with the first 11 detections
- **Increase the quantity**: precise population parameter constrain → origin and evolution of compact binary system
- **Increase the quality**: determination of neutron star EoS
- **Increase the localization precision**: EM counterpart, Hubble constant constrain