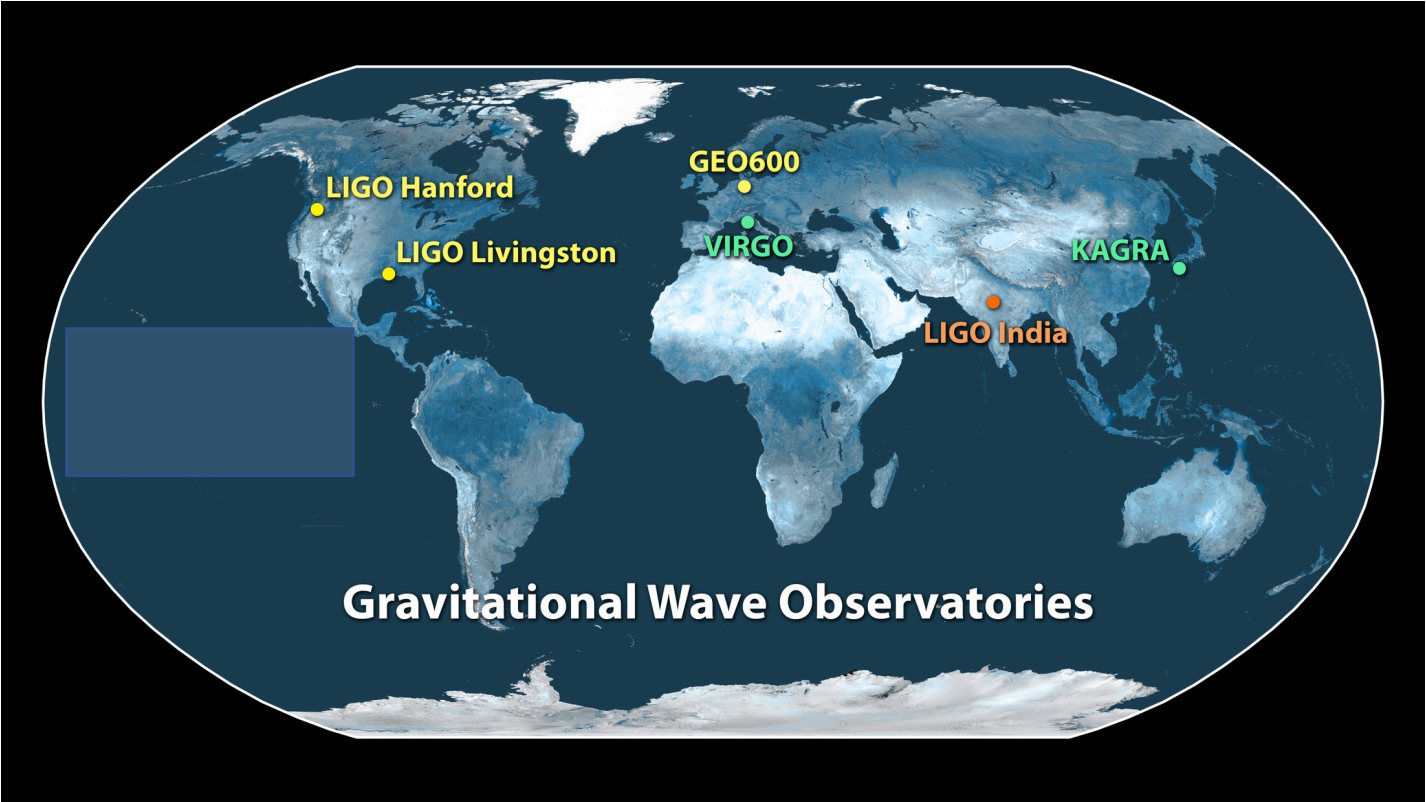


Gravitational waves: review of LIGO-Virgo results, current interpretations, and prospects

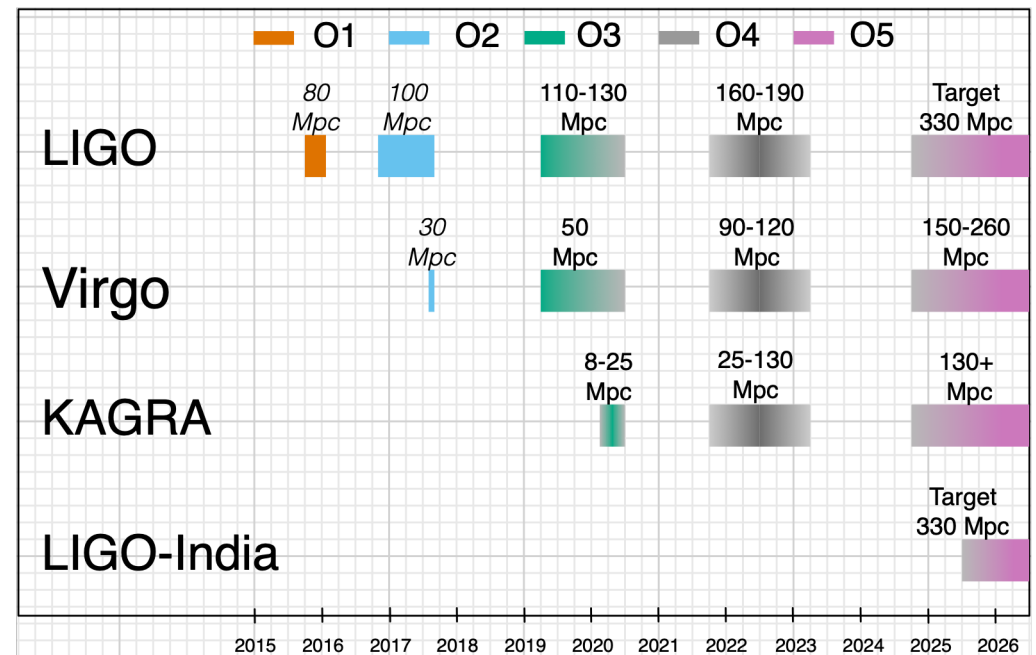
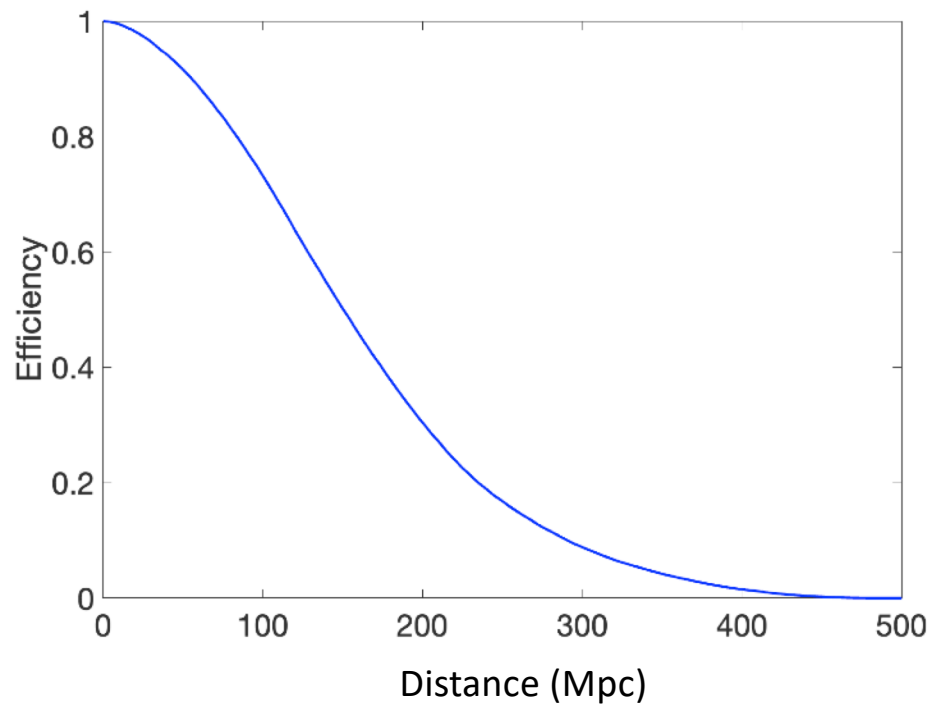
Tania Regimbau, Annecy, November 22th

The terrestrial detector network



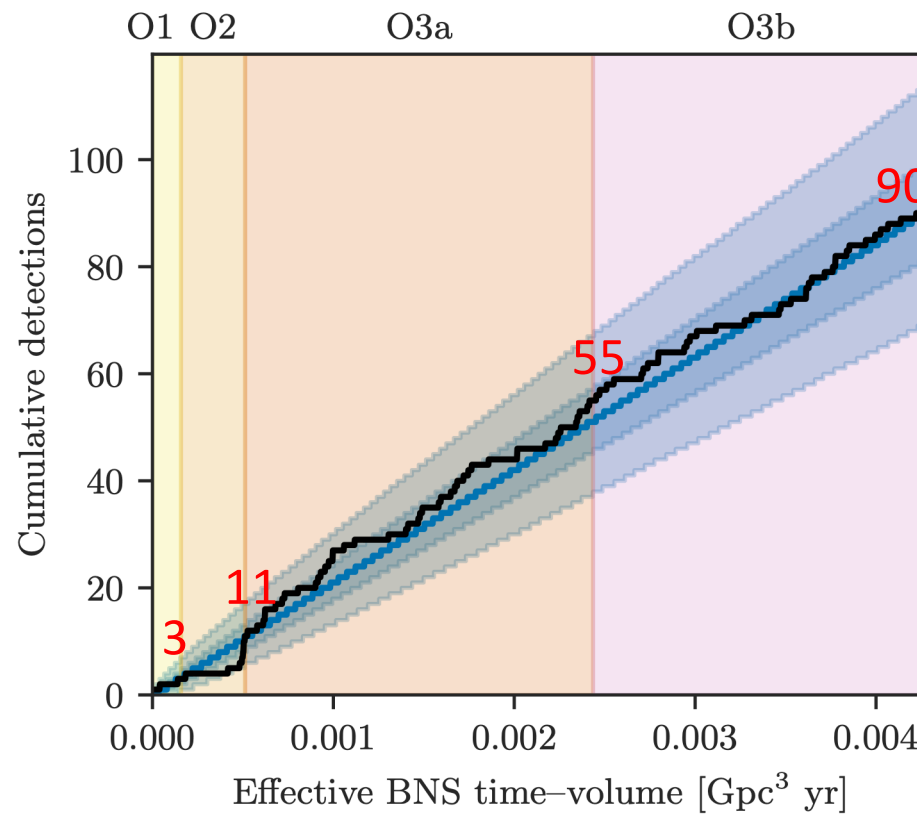
Detection range and observing scenario

Provides an estimate of the sensitivity of a detector, as the average distance at which a NS-NS binary with masses 1.4+1.4 can be observed with an SNR=8.



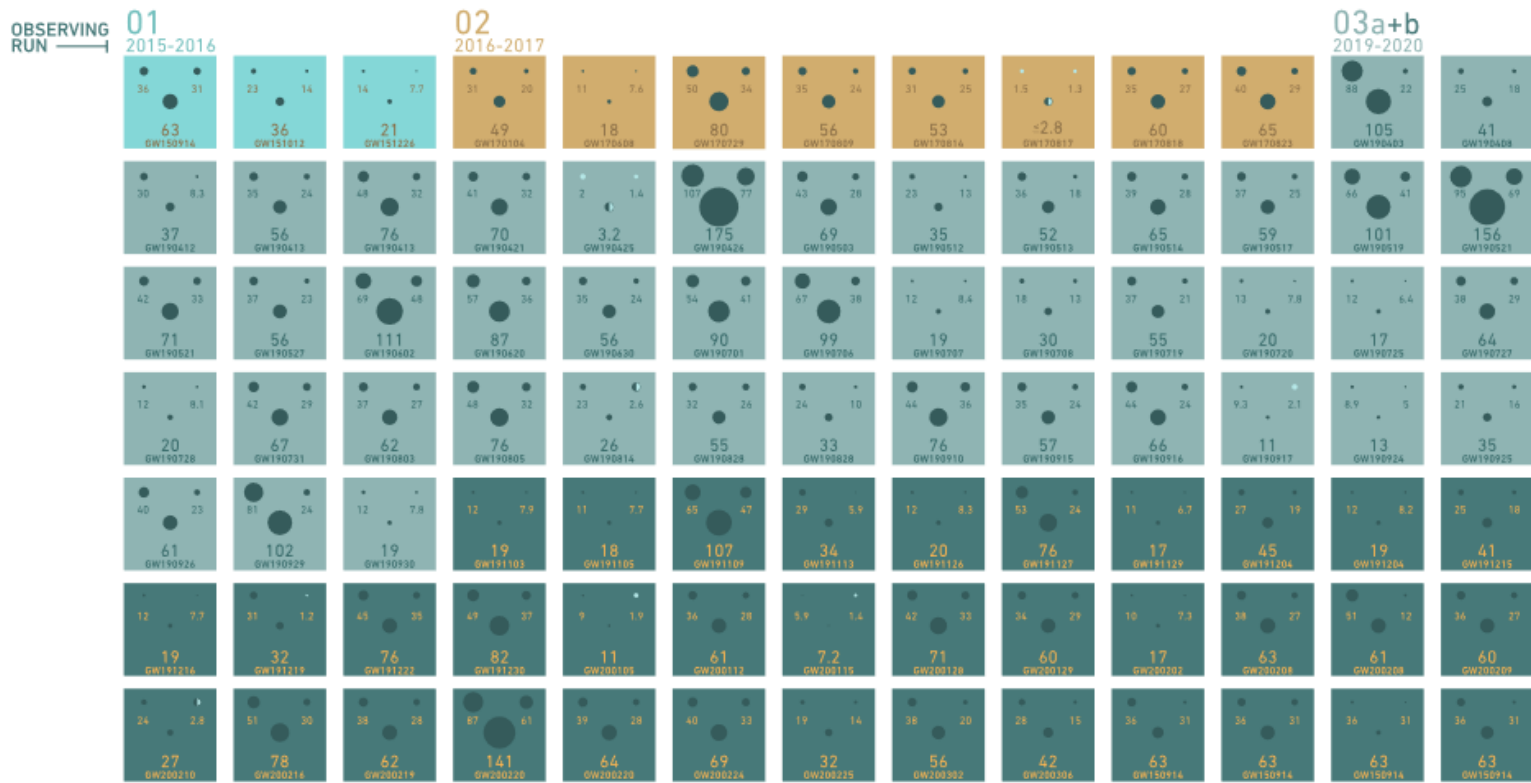
Detections

35 new detections in O3b with $p_{\text{astro}} > 0.5$

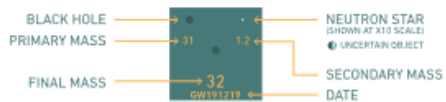


GRAVITATIONAL WAVE **MERGER** DETECTIONS

→ SINCE 2015



KEY



UNITS ARE SOLAR MASSES
 1 SOLAR MASS = 1.989×10^{30} kg

Note that the mass estimates shown here do not include uncertainties, which is why the final mass is sometimes larger than the sum of the primary and secondary masses. In actuality, the final mass is smaller than the primary plus the secondary mass.

The events listed here pass one of two thresholds for detection. They either have a probability of being astrophysical of at least 50%, or they pass a false alarm rate threshold of less than 1 per 3 years.



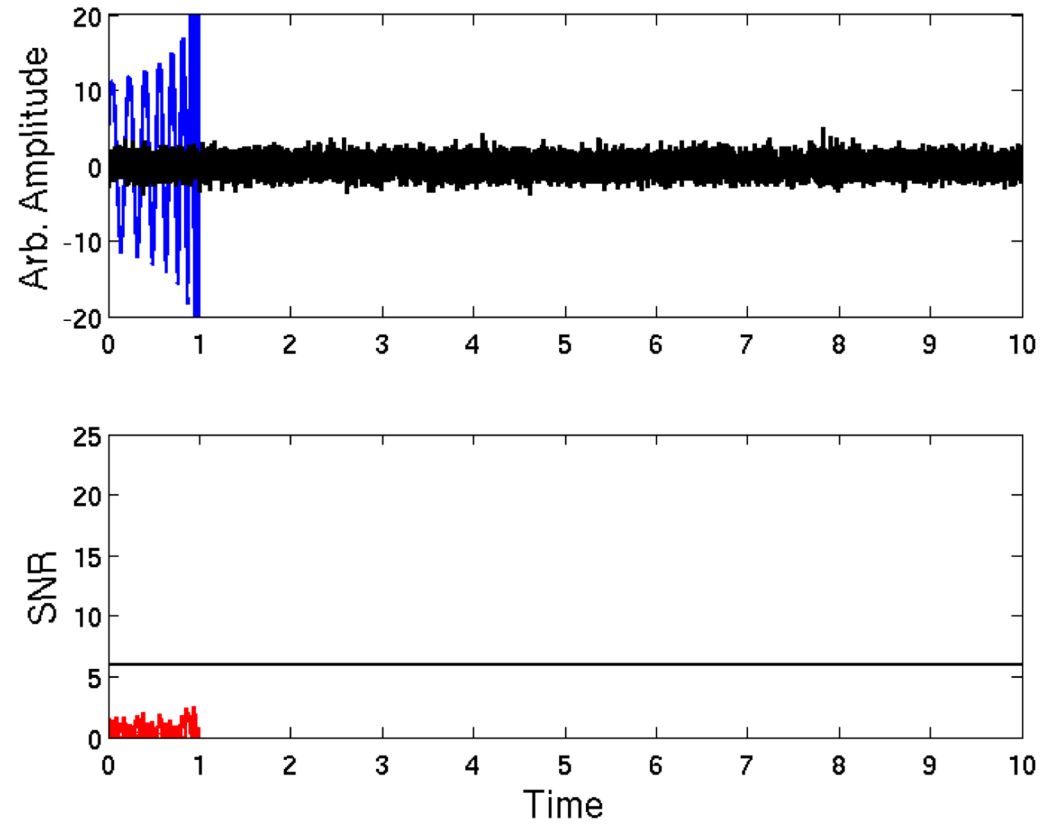
GWTC-3 papers

- GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo During the Second Part of the Third Observing Run; [arXiv:2111.03606](https://arxiv.org/abs/2111.03606)
- The population of merging compact binaries inferred using gravitational waves through GWTC-3; [arXiv:2111.03606](https://arxiv.org/abs/2111.03606)

The run O3b

- from April 1st 2019 to March 27th 2020 divided in 6 months chunks.
- 3 pipelines based on match filtering GstLAL, PyCBC, MBTA + unmodelled CWB
- 39 sources reported in low-latency searches (18 survived) and 17 sources detected in offline searches.
 - first observations of NS-BHs, no BNS
 - no coincident observation with EM
 - number of detections in agreement with predictions at the end of O3a

Match filtering



Some measured quantities

- Chirp mass:

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

- Effective spin:

$$\chi_{\text{eff}} = \frac{(m_1 \vec{\chi}_1 + m_2 \vec{\chi}_2) \cdot \hat{L}_N}{M}$$

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	20.0 ^{+3.7} _{-1.8}	8.34 ^{+0.66} _{-0.57}	11.8 ^{+6.2} _{-2.2}	7.9 ^{+1.7} _{-2.4}	0.21 ^{+0.16} _{-0.10}	0.99 ^{+0.50} _{-0.47}	0.20 ^{+0.09} _{-0.09}	19.0 ^{+3.8} _{-1.7}	0.75 ^{+0.06} _{-0.05}	2500	8.9 ^{+0.3} _{-0.5}
GW191105_143521	18.5 ^{+2.1} _{-1.3}	7.82 ^{+0.61} _{-0.45}	10.7 ^{+3.7} _{-1.6}	7.7 ^{+1.4} _{-1.9}	-0.02 ^{+0.13} _{-0.09}	1.15 ^{+0.43} _{-0.48}	0.23 ^{+0.07} _{-0.09}	17.6 ^{+2.1} _{-1.2}	0.67 ^{+0.04} _{-0.05}	640	9.7 ^{+0.3} _{-0.5}
GW191109_010717	112 ⁺²⁰ ₋₁₆	47.5 ^{+9.6} _{-7.5}	65 ⁺¹¹ ₋₁₁	47 ⁺¹⁵ ₋₁₃	-0.29 ^{+0.42} _{-0.31}	1.29 ^{+1.13} _{-0.65}	0.25 ^{+0.18} _{-0.12}	107 ⁺¹⁸ ₋₁₅	0.61 ^{+0.18} _{-0.19}	1600	17.3 ^{+0.5} _{-0.5}
GW191113_071753	34.5 ^{+10.5} _{-9.8}	10.7 ^{+1.1} _{-1.0}	29 ⁺¹² ₋₁₄	5.9 ^{+4.4} _{-1.3}	0.00 ^{+0.37} _{-0.29}	1.37 ^{+1.15} _{-0.62}	0.26 ^{+0.18} _{-0.11}	34 ⁺¹¹ ₋₁₀	0.45 ^{+0.33} _{-0.11}	3600	7.9 ^{+0.5} _{-1.1}
GW191126_115259	20.7 ^{+3.4} _{-2.0}	8.65 ^{+0.95} _{-0.71}	12.1 ^{+5.5} _{-2.2}	8.3 ^{+1.9} _{-2.4}	0.21 ^{+0.15} _{-0.11}	1.62 ^{+0.74} _{-0.74}	0.30 ^{+0.12} _{-0.13}	19.6 ^{+3.5} _{-2.0}	0.75 ^{+0.06} _{-0.05}	1400	8.3 ^{+0.2} _{-0.5}
GW191127_050227	80 ⁺³⁹ ₋₂₂	29.9 ^{+11.7} _{-9.1}	53 ⁺⁴⁷ ₋₂₀	24 ⁺¹⁷ ₋₁₄	0.18 ^{+0.34} _{-0.36}	3.4 ^{+3.1} _{-1.9}	0.57 ^{+0.40} _{-0.29}	76 ⁺³⁹ ₋₂₁	0.75 ^{+0.13} _{-0.29}	980	9.2 ^{+0.7} _{-0.6}
GW191129_134029	17.5 ^{+2.4} _{-1.2}	7.31 ^{+0.43} _{-0.28}	10.7 ^{+4.1} _{-2.1}	6.7 ^{+1.5} _{-1.7}	0.06 ^{+0.16} _{-0.08}	0.79 ^{+0.26} _{-0.33}	0.16 ^{+0.05} _{-0.06}	16.8 ^{+2.5} _{-1.2}	0.69 ^{+0.03} _{-0.05}	850	13.1 ^{+0.2} _{-0.3}
GW191204_110529	47.2 ^{+9.2} _{-8.0}	19.8 ^{+3.6} _{-3.3}	27.3 ^{+11.0} _{-6.0}	19.3 ^{+5.6} _{-6.0}	0.05 ^{+0.26} _{-0.27}	1.8 ^{+1.7} _{-1.1}	0.34 ^{+0.25} _{-0.18}	45.0 ^{+8.6} _{-7.6}	0.71 ^{+0.12} _{-0.11}	3700	8.8 ^{+0.4} _{-0.6}
GW191204_171526	20.21 ^{+1.70} _{-0.96}	8.55 ^{+0.38} _{-0.27}	11.9 ^{+3.3} _{-1.8}	8.2 ^{+1.4} _{-1.6}	0.16 ^{+0.08} _{-0.05}	0.65 ^{+0.19} _{-0.25}	0.13 ^{+0.04} _{-0.05}	19.21 ^{+1.79} _{-0.95}	0.73 ^{+0.03} _{-0.03}	350	17.5 ^{+0.2} _{-0.2}
GW191215_223052	43.3 ^{+5.3} _{-4.3}	18.4 ^{+2.2} _{-1.7}	24.9 ^{+7.1} _{-4.1}	18.1 ^{+3.8} _{-4.1}	-0.04 ^{+0.17} _{-0.21}	1.93 ^{+0.89} _{-0.86}	0.35 ^{+0.13} _{-0.14}	41.4 ^{+5.1} _{-4.1}	0.68 ^{+0.07} _{-0.07}	530	11.2 ^{+0.3} _{-0.4}
GW191216_213338	19.81 ^{+2.69} _{-0.94}	8.33 ^{+0.22} _{-0.19}	12.1 ^{+4.6} _{-2.3}	7.7 ^{+1.6} _{-1.9}	0.11 ^{+0.13} _{-0.06}	0.34 ^{+0.12} _{-0.13}	0.07 ^{+0.02} _{-0.03}	18.87 ^{+2.80} _{-0.94}	0.70 ^{+0.03} _{-0.04}	490	18.6 ^{+0.2} _{-0.2}
<i>GW191219_163120</i>	32.3 ^{+2.2} _{-2.7}	4.32 ^{+0.12} _{-0.17}	31.1 ^{+2.2} _{-2.8}	1.17 ^{+0.07} _{-0.06}	0.00 ^{+0.07} _{-0.09}	0.55 ^{+0.25} _{-0.16}	0.11 ^{+0.05} _{-0.03}	32.2 ^{+2.2} _{-2.7}	0.14 ^{+0.06} _{-0.06}	1500	9.1 ^{+0.5} _{-0.8}
GW191222_033537	79 ⁺¹⁶ ₋₁₁	33.8 ^{+7.1} _{-5.0}	45.1 ^{+10.9} _{-8.0}	34.7 ^{+9.3} _{-10.5}	-0.04 ^{+0.20} _{-0.25}	3.0 ^{+1.7} _{-1.7}	0.51 ^{+0.23} _{-0.26}	75.5 ^{+15.3} _{-9.9}	0.67 ^{+0.08} _{-0.11}	2000	12.5 ^{+0.2} _{-0.3}
GW191230_180458	86 ⁺¹⁹ ₋₁₂	36.5 ^{+8.2} _{-5.6}	49.4 ^{+14.0} _{-9.6}	37 ⁺¹¹ ₋₁₂	-0.05 ^{+0.26} _{-0.31}	4.3 ^{+2.1} _{-1.9}	0.69 ^{+0.26} _{-0.27}	82 ⁺¹⁷ ₋₁₁	0.68 ^{+0.11} _{-0.13}	1100	10.4 ^{+0.3} _{-0.4}
<i>GW200105_162426</i>	11.0 ^{+1.5} _{-1.4}	3.42 ^{+0.08} _{-0.08}	9.0 ^{+1.7} _{-1.7}	1.91 ^{+0.33} _{-0.24}	0.00 ^{+0.13} _{-0.18}	0.27 ^{+0.12} _{-0.11}	0.06 ^{+0.02} _{-0.02}	10.7 ^{+1.5} _{-1.4}	0.43 ^{+0.05} _{-0.02}	7900	13.7 ^{+0.2} _{-0.4}
GW200112_155838	63.9 ^{+5.7} _{-4.6}	27.4 ^{+2.6} _{-2.1}	35.6 ^{+6.7} _{-4.5}	28.3 ^{+4.4} _{-5.9}	0.06 ^{+0.15} _{-0.15}	1.25 ^{+0.43} _{-0.46}	0.24 ^{+0.07} _{-0.08}	60.8 ^{+5.3} _{-4.3}	0.71 ^{+0.06} _{-0.06}	4300	19.8 ^{+0.1} _{-0.2}
GW200115_042309	7.4 ^{+1.8} _{-1.7}	2.43 ^{+0.05} _{-0.07}	5.9 ^{+2.0} _{-2.5}	1.44 ^{+0.85} _{-0.29}	-0.15 ^{+0.24} _{-0.42}	0.29 ^{+0.15} _{-0.10}	0.06 ^{+0.03} _{-0.02}	7.2 ^{+1.8} _{-1.7}	0.42 ^{+0.09} _{-0.05}	370	11.3 ^{+0.3} _{-0.5}
GW200128_022011	75 ⁺¹⁷ ₋₁₂	32.0 ^{+7.5} _{-5.5}	42.2 ^{+11.6} _{-8.1}	32.6 ^{+9.5} _{-9.2}	0.12 ^{+0.24} _{-0.25}	3.4 ^{+2.1} _{-1.8}	0.56 ^{+0.28} _{-0.28}	71 ⁺¹⁶ ₋₁₁	0.74 ^{+0.10} _{-0.10}	2600	10.6 ^{+0.3} _{-0.4}
GW200129_065458	63.4 ^{+4.3} _{-3.6}	27.2 ^{+2.1} _{-2.3}	34.5 ^{+9.9} _{-3.2}	28.9 ^{+3.4} _{-9.3}	0.11 ^{+0.11} _{-0.16}	0.90 ^{+0.29} _{-0.38}	0.18 ^{+0.05} _{-0.07}	60.3 ^{+4.0} _{-3.3}	0.73 ^{+0.06} _{-0.05}	130	26.8 ^{+0.2} _{-0.2}

Less massive NS

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	20.0 ^{+3.7} _{-1.8}	8.34 ^{+0.66} _{-0.57}	11.8 ^{+6.2} _{-2.2}	7.9 ^{+1.7} _{-2.4}	0.21 ^{+0.16} _{-0.10}	0.99 ^{+0.50} _{-0.47}	0.20 ^{+0.09} _{-0.09}	19.0 ^{+3.8} _{-1.7}	0.75 ^{+0.06} _{-0.05}	2500	8.9 ^{+0.3} _{-0.5}
GW191105_143521	18.5 ^{+2.1} _{-1.3}	7.82 ^{+0.61} _{-0.45}	10.7 ^{+3.7} _{-1.6}	7.7 ^{+1.4} _{-1.9}	-0.02 ^{+0.13} _{-0.09}	1.15 ^{+0.43} _{-0.48}	0.23 ^{+0.07} _{-0.09}	17.6 ^{+2.1} _{-1.2}	0.67 ^{+0.04} _{-0.05}	640	9.7 ^{+0.3} _{-0.5}
GW191109_010717	112 ⁺²⁰ ₋₁₆	47.5 ^{+9.6} _{-7.5}	65 ⁺¹¹ ₋₁₁	47 ⁺¹⁵ ₋₁₃	-0.29 ^{+0.42} _{-0.31}	1.29 ^{+1.13} _{-0.65}	0.25 ^{+0.18} _{-0.12}	107 ⁺¹⁸ ₋₁₅	0.61 ^{+0.18} _{-0.19}	1600	17.3 ^{+0.5} _{-0.5}
GW191113_071753	34.5 ^{+10.5} _{-9.8}	10.7 ^{+1.1} _{-1.0}	29 ⁺¹² ₋₁₄	5.9 ^{+4.4} _{-1.3}	0.00 ^{+0.37} _{-0.29}	1.37 ^{+1.15} _{-0.62}	0.26 ^{+0.18} _{-0.11}	34 ⁺¹¹ ₋₁₀	0.45 ^{+0.33} _{-0.11}	3600	7.9 ^{+0.5} _{-1.1}
GW191126_115259	20.7 ^{+3.4} _{-2.0}	8.65 ^{+0.95} _{-0.71}	12.1 ^{+5.5} _{-2.2}	8.3 ^{+1.9} _{-2.4}	0.21 ^{+0.15} _{-0.11}	1.62 ^{+0.74} _{-0.74}	0.30 ^{+0.12} _{-0.13}	19.6 ^{+3.5} _{-2.0}	0.75 ^{+0.06} _{-0.05}	1400	8.3 ^{+0.2} _{-0.5}
GW191127_050227	80 ⁺³⁹ ₋₂₂	29.9 ^{+11.7} _{-9.1}	53 ⁺⁴⁷ ₋₂₀	24 ⁺¹⁷ ₋₁₄	0.18 ^{+0.34} _{-0.36}	3.4 ^{+3.1} _{-1.9}	0.57 ^{+0.40} _{-0.29}	76 ⁺³⁹ ₋₂₁	0.75 ^{+0.13} _{-0.29}	980	9.2 ^{+0.7} _{-0.6}
GW191129_134029	17.5 ^{+2.4} _{-1.2}	7.31 ^{+0.43} _{-0.28}	10.7 ^{+4.1} _{-2.1}	6.7 ^{+1.5} _{-1.7}	0.06 ^{+0.16} _{-0.08}	0.79 ^{+0.26} _{-0.33}	0.16 ^{+0.05} _{-0.06}	16.8 ^{+2.5} _{-1.2}	0.69 ^{+0.03} _{-0.05}	850	13.1 ^{+0.2} _{-0.3}
GW191204_110529	47.2 ^{+9.2} _{-8.0}	19.8 ^{+3.6} _{-3.3}	27.3 ^{+11.0} _{-6.0}	19.3 ^{+5.6} _{-6.0}	0.05 ^{+0.26} _{-0.27}	1.8 ^{+1.7} _{-1.1}	0.34 ^{+0.25} _{-0.18}	45.0 ^{+8.6} _{-7.6}	0.71 ^{+0.12} _{-0.11}	3700	8.8 ^{+0.4} _{-0.6}
GW191204_171526	20.21 ^{+1.70} _{-0.96}	8.55 ^{+0.38} _{-0.27}	11.9 ^{+3.3} _{-1.8}	8.2 ^{+1.4} _{-1.6}	0.16 ^{+0.08} _{-0.05}	0.65 ^{+0.19} _{-0.25}	0.13 ^{+0.04} _{-0.05}	19.21 ^{+1.79} _{-0.95}	0.73 ^{+0.03} _{-0.03}	350	17.5 ^{+0.2} _{-0.2}
GW191215_223052	43.3 ^{+5.3} _{-4.3}	18.4 ^{+2.2} _{-1.7}	24.9 ^{+7.1} _{-4.1}	18.1 ^{+3.8} _{-4.1}	-0.04 ^{+0.17} _{-0.21}	1.93 ^{+0.89} _{-0.86}	0.35 ^{+0.13} _{-0.14}	41.4 ^{+5.1} _{-4.1}	0.68 ^{+0.07} _{-0.07}	530	11.2 ^{+0.3} _{-0.4}
GW191216_213338	19.81 ^{+2.69} _{-0.94}	8.33 ^{+0.22} _{-0.19}	12.1 ^{+4.6} _{-2.3}	7.7 ^{+1.6} _{-1.9}	0.11 ^{+0.13} _{-0.06}	0.34 ^{+0.12} _{-0.13}	0.07 ^{+0.02} _{-0.03}	18.87 ^{+2.80} _{-0.94}	0.70 ^{+0.03} _{-0.04}	490	18.6 ^{+0.2} _{-0.2}
<i>GW191219_163120</i>	32.3 ^{+2.2} _{-2.7}	4.32 ^{+0.12} _{-0.17}	31.1 ^{+2.2} _{-2.8}	1.17 ^{+0.07} _{-0.06}	0.00 ^{+0.07} _{-0.09}	0.55 ^{+0.25} _{-0.16}	0.11 ^{+0.05} _{-0.03}	32.2 ^{+2.2} _{-2.7}	0.14 ^{+0.06} _{-0.06}	1500	9.1 ^{+0.5} _{-0.8}
GW191222_033537	79 ⁺¹⁶ ₋₁₁	33.8 ^{+7.1} _{-5.0}	45.1 ^{+10.9} _{-8.0}	34.7 ^{+9.3} _{-10.5}	-0.04 ^{+0.20} _{-0.25}	3.0 ^{+1.7} _{-1.7}	0.51 ^{+0.23} _{-0.26}	75.5 ^{+15.3} _{-9.9}	0.67 ^{+0.08} _{-0.11}	2000	12.5 ^{+0.2} _{-0.3}
GW191230_180458	86 ⁺¹⁹ ₋₁₂	36.5 ^{+8.2} _{-5.6}	49.4 ^{+14.0} _{-9.6}	37 ⁺¹¹ ₋₁₂	-0.05 ^{+0.26} _{-0.31}	4.3 ^{+2.1} _{-1.9}	0.69 ^{+0.26} _{-0.27}	82 ⁺¹⁷ ₋₁₁	0.68 ^{+0.11} _{-0.13}	1100	10.4 ^{+0.3} _{-0.4}
<i>GW200105_162426</i>	11.0 ^{+1.5} _{-1.4}	3.42 ^{+0.08} _{-0.08}	9.0 ^{+1.7} _{-1.7}	1.91 ^{+0.33} _{-0.24}	0.00 ^{+0.13} _{-0.18}	0.27 ^{+0.12} _{-0.11}	0.06 ^{+0.02} _{-0.02}	10.7 ^{+1.5} _{-1.4}	0.43 ^{+0.05} _{-0.02}	7900	13.7 ^{+0.3} _{-0.3}
GW200112_155838	63.9 ^{+5.7} _{-4.6}	27.4 ^{+2.6} _{-2.1}	35.6 ^{+6.7} _{-4.5}	28.3 ^{+4.4} _{-5.9}	0.06 ^{+0.15} _{-0.15}	1.25 ^{+0.43} _{-0.46}	0.24 ^{+0.07} _{-0.08}	60.8 ^{+5.3} _{-4.3}	0.71 ^{+0.06} _{-0.06}	4300	19.8 ^{+0.1} _{-0.2}
GW200115_042309	7.4 ^{+1.8} _{-1.7}	2.43 ^{+0.05} _{-0.07}	5.9 ^{+2.0} _{-2.5}	1.44 ^{+0.85} _{-0.29}	-0.15 ^{+0.24} _{-0.42}	0.29 ^{+0.15} _{-0.10}	0.06 ^{+0.03} _{-0.02}	7.2 ^{+1.8} _{-1.7}	0.42 ^{+0.09} _{-0.05}	370	11.3 ^{+0.3} _{-0.5}
GW200128_022011	75 ⁺¹⁷ ₋₁₂	32.0 ^{+7.5} _{-5.5}	42.2 ^{+11.6} _{-8.1}	32.6 ^{+9.5} _{-9.2}	0.12 ^{+0.24} _{-0.25}	3.4 ^{+2.1} _{-1.8}	0.56 ^{+0.28} _{-0.28}	71 ⁺¹⁶ ₋₁₁	0.74 ^{+0.10} _{-0.10}	2600	10.6 ^{+0.3} _{-0.4}
GW200129_065458	63.4 ^{+4.3} _{-3.6}	27.2 ^{+2.1} _{-2.3}	34.5 ^{+9.9} _{-3.2}	28.9 ^{+3.4} _{-9.3}	0.11 ^{+0.11} _{-0.16}	0.90 ^{+0.29} _{-0.38}	0.18 ^{+0.05} _{-0.07}	60.3 ^{+4.0} _{-3.3}	0.73 ^{+0.06} _{-0.05}	130	26.8 ^{+0.2} _{-0.2}

$P_{\text{astro}} = 35\%$ but clearly above the background

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	20.0 ^{+3.7} _{-1.8}	8.34 ^{+0.66} _{-0.57}	11.8 ^{+6.2} _{-2.2}	7.9 ^{+1.7} _{-2.4}	0.21 ^{+0.16} _{-0.10}	0.99 ^{+0.50} _{-0.47}	0.20 ^{+0.09} _{-0.09}	19.0 ^{+3.8} _{-1.7}	0.75 ^{+0.06} _{-0.05}	2500	8.9 ^{+0.3} _{-0.5}
GW191105_143521	18.5 ^{+2.1} _{-1.3}	7.82 ^{+0.61} _{-0.45}	10.7 ^{+3.7} _{-1.6}	7.7 ^{+1.4} _{-1.9}	-0.02 ^{+0.13} _{-0.09}	1.15 ^{+0.43} _{-0.48}	0.23 ^{+0.07} _{-0.09}	17.6 ^{+2.1} _{-1.2}	0.67 ^{+0.04} _{-0.05}	640	9.7 ^{+0.3} _{-0.5}
GW191109_010717	112 ⁺²⁰ ₋₁₆	47.5 ^{+9.6} _{-7.5}	65 ⁺¹¹ ₋₁₁	47 ⁺¹⁵ ₋₁₃	-0.29 ^{+0.42} _{-0.31}	1.29 ^{+1.13} _{-0.65}	0.25 ^{+0.18} _{-0.12}	107 ⁺¹⁸ ₋₁₅	0.61 ^{+0.18} _{-0.19}	1600	17.3 ^{+0.5} _{-0.5}
GW191113_071753	34.5 ^{+10.5} _{-9.8}	10.7 ^{+1.1} _{-1.0}	29 ⁺¹² ₋₁₄	5.9 ^{+4.4} _{-1.3}	0.00 ^{+0.37} _{-0.29}	1.37 ^{+1.15} _{-0.62}	0.26 ^{+0.18} _{-0.11}	34 ⁺¹¹ ₋₁₀	0.45 ^{+0.33} _{-0.11}	3600	7.9 ^{+0.5} _{-1.1}
GW191126_115259	20.7 ^{+3.4} _{-2.0}	8.65 ^{+0.95} _{-0.71}	12.1 ^{+5.5} _{-2.2}	8.3 ^{+1.9} _{-2.4}	0.21 ^{+0.15} _{-0.11}	1.62 ^{+0.74} _{-0.74}	0.30 ^{+0.12} _{-0.13}	19.6 ^{+3.5} _{-2.0}	0.75 ^{+0.06} _{-0.05}	1400	8.3 ^{+0.2} _{-0.5}
GW191127_050227	80 ⁺³⁹ ₋₂₂	29.9 ^{+11.7} _{-9.1}	53 ⁺⁴⁷ ₋₂₀	24 ⁺¹⁷ ₋₁₄	0.18 ^{+0.34} _{-0.36}	3.4 ^{+3.1} _{-1.9}	0.57 ^{+0.40} _{-0.29}	76 ⁺³⁹ ₋₂₁	0.75 ^{+0.13} _{-0.29}	980	9.2 ^{+0.7} _{-0.6}
GW191129_134029	17.5 ^{+2.4} _{-1.2}	7.31 ^{+0.43} _{-0.28}	10.7 ^{+4.1} _{-2.1}	6.7 ^{+1.5} _{-1.7}	0.06 ^{+0.16} _{-0.08}	0.79 ^{+0.26} _{-0.33}	0.16 ^{+0.05} _{-0.06}	16.8 ^{+2.5} _{-1.2}	0.69 ^{+0.03} _{-0.05}	850	13.1 ^{+0.2} _{-0.3}
GW191204_110529	47.2 ^{+9.2} _{-8.0}	19.8 ^{+3.6} _{-3.3}	27.3 ^{+11.0} _{-6.0}	19.3 ^{+5.6} _{-6.0}	0.05 ^{+0.26} _{-0.27}	1.8 ^{+1.7} _{-1.1}	0.34 ^{+0.25} _{-0.18}	45.0 ^{+8.6} _{-7.6}	0.71 ^{+0.12} _{-0.11}	3700	8.8 ^{+0.4} _{-0.6}
GW191204_171526	20.21 ^{+1.70} _{-0.96}	8.55 ^{+0.38} _{-0.27}	11.9 ^{+3.3} _{-1.8}	8.2 ^{+1.4} _{-1.6}	0.16 ^{+0.08} _{-0.05}	0.65 ^{+0.19} _{-0.25}	0.13 ^{+0.04} _{-0.05}	19.21 ^{+1.79} _{-0.95}	0.73 ^{+0.03} _{-0.03}	350	17.5 ^{+0.2} _{-0.2}
GW191215_223052	43.3 ^{+5.3} _{-4.3}	18.4 ^{+2.2} _{-1.7}	24.9 ^{+7.1} _{-4.1}	18.1 ^{+3.8} _{-4.1}	-0.04 ^{+0.17} _{-0.21}	1.93 ^{+0.89} _{-0.86}	0.35 ^{+0.13} _{-0.14}	41.4 ^{+5.1} _{-4.1}	0.68 ^{+0.07} _{-0.07}	530	11.2 ^{+0.3} _{-0.4}
GW191216_213338	19.81 ^{+2.69} _{-0.94}	8.33 ^{+0.22} _{-0.19}	12.1 ^{+4.6} _{-2.3}	7.7 ^{+1.6} _{-1.9}	0.11 ^{+0.13} _{-0.06}	0.34 ^{+0.12} _{-0.13}	0.07 ^{+0.02} _{-0.03}	18.87 ^{+2.80} _{-0.94}	0.70 ^{+0.03} _{-0.04}	490	18.6 ^{+0.2} _{-0.2}
<i>GW191219_163120</i>	32.3 ^{+2.2} _{-2.7}	4.32 ^{+0.12} _{-0.17}	31.1 ^{+2.2} _{-2.8}	1.17 ^{+0.07} _{-0.06}	0.00 ^{+0.07} _{-0.09}	0.55 ^{+0.25} _{-0.16}	0.11 ^{+0.05} _{-0.03}	32.2 ^{+2.2} _{-2.7}	0.14 ^{+0.06} _{-0.06}	1500	9.1 ^{+0.5} _{-0.8}
GW191222_033537	79 ⁺¹⁶ ₋₁₁	33.8 ^{+7.1} _{-5.0}	45.1 ^{+10.9} _{-8.0}	34.7 ^{+9.3} _{-10.5}	-0.04 ^{+0.20} _{-0.25}	3.0 ^{+1.7} _{-1.7}	0.51 ^{+0.23} _{-0.26}	75.5 ^{+15.3} _{-9.9}	0.67 ^{+0.08} _{-0.11}	2000	12.5 ^{+0.2} _{-0.3}
GW191230_180458	86 ⁺¹⁹ ₋₁₂	36.5 ^{+8.2} _{-5.6}	49.4 ^{+14.0} _{-9.6}	37 ⁺¹¹ ₋₁₂	-0.05 ^{+0.26} _{-0.31}	4.3 ^{+2.1} _{-1.9}	0.69 ^{+0.26} _{-0.27}	82 ⁺¹⁷ ₋₁₁	0.68 ^{+0.11} _{-0.13}	1100	10.4 ^{+0.3} _{-0.4}
<i>GW200105_162426</i>	11.0 ^{+1.5} _{-1.4}	3.42 ^{+0.08} _{-0.08}	9.0 ^{+1.7} _{-1.7}	1.91 ^{+0.33} _{-0.24}	0.00 ^{+0.13} _{-0.18}	0.27 ^{+0.12} _{-0.11}	0.06 ^{+0.02} _{-0.02}	10.7 ^{+1.5} _{-1.4}	0.43 ^{+0.05} _{-0.02}	7900	13.7 ^{+0.2} _{-0.4}
GW200112_155838	63.9 ^{+5.7} _{-4.6}	27.4 ^{+2.6} _{-2.1}	35.6 ^{+6.7} _{-4.5}	28.3 ^{+4.4} _{-5.9}	0.06 ^{+0.15} _{-0.15}	1.25 ^{+0.43} _{-0.46}	0.24 ^{+0.07} _{-0.08}	60.8 ^{+5.3} _{-4.3}	0.71 ^{+0.06} _{-0.06}	4300	19.8 ^{+0.1} _{-0.2}
GW200115_042309	7.4 ^{+1.8} _{-1.7}	2.43 ^{+0.05} _{-0.07}	5.9 ^{+2.0} _{-2.5}	1.44 ^{+0.85} _{-0.29}	-0.15 ^{+0.24} _{-0.42}	0.29 ^{+0.15} _{-0.10}	0.06 ^{+0.03} _{-0.02}	7.2 ^{+1.8} _{-1.7}	0.42 ^{+0.09} _{-0.05}	370	11.3 ^{+0.3} _{-0.3}
GW200128_022011	75 ⁺¹⁷ ₋₁₂	32.0 ^{+7.5} _{-5.5}	42.2 ^{+11.6} _{-8.1}	32.6 ^{+9.5} _{-9.2}	0.12 ^{+0.24} _{-0.25}	3.4 ^{+2.1} _{-1.8}	0.56 ^{+0.28} _{-0.28}	71 ⁺¹⁶ ₋₁₁	0.74 ^{+0.10} _{-0.10}	2600	10.6 ^{+0.3} _{-0.4}
GW200129_065458	63.4 ^{+4.3} _{-3.6}	27.2 ^{+2.1} _{-2.3}	34.5 ^{+9.9} _{-3.2}	28.9 ^{+3.4} _{-9.3}	0.11 ^{+0.11} _{-0.16}	0.90 ^{+0.29} _{-0.38}	0.18 ^{+0.05} _{-0.07}	60.3 ^{+4.0} _{-3.3}	0.73 ^{+0.06} _{-0.05}	130	26.8 ^{+0.2} _{-0.2}

Evidence for BH spin opposite to the orbital angular momentum. Dynamical formation channel?

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW200202_154313	$17.58^{+1.78}_{-0.67}$	$7.49^{+0.24}_{-0.20}$	$10.1^{+3.5}_{-1.4}$	$7.3^{+1.1}_{-1.7}$	$0.04^{+0.13}_{-0.06}$	$0.41^{+0.15}_{-0.16}$	$0.09^{+0.03}_{-0.03}$	$16.76^{+1.87}_{-0.66}$	$0.69^{+0.03}_{-0.04}$	170	$10.8^{+0.2}_{-0.4}$
GW200208_130117	$65.4^{+7.8}_{-6.8}$	$27.7^{+3.6}_{-3.1}$	$37.8^{+9.2}_{-6.2}$	$27.4^{+6.1}_{-7.4}$	$-0.07^{+0.22}_{-0.27}$	$2.23^{+1.00}_{-0.85}$	$0.40^{+0.15}_{-0.14}$	$62.5^{+7.3}_{-6.4}$	$0.66^{+0.09}_{-0.13}$	30	$10.8^{+0.3}_{-0.4}$
GW200208_222617	63^{+100}_{-25}	$19.6^{+10.7}_{-5.1}$	51^{+104}_{-30}	$12.3^{+9.0}_{-5.7}$	$0.45^{+0.43}_{-0.44}$	$4.1^{+4.4}_{-1.9}$	$0.66^{+0.54}_{-0.28}$	61^{+100}_{-25}	$0.83^{+0.14}_{-0.27}$	2000	$7.4^{+1.4}_{-1.2}$
GW200209_085452	$62.6^{+13.9}_{-9.4}$	$26.7^{+6.0}_{-4.2}$	$35.6^{+10.5}_{-6.8}$	$27.1^{+7.8}_{-7.8}$	$-0.12^{+0.24}_{-0.30}$	$3.4^{+1.9}_{-1.8}$	$0.57^{+0.25}_{-0.26}$	$59.9^{+13.1}_{-8.9}$	$0.66^{+0.10}_{-0.12}$	730	$9.6^{+0.4}_{-0.5}$
GW200210_092254	$27.0^{+7.1}_{-4.3}$	$6.56^{+0.38}_{-0.40}$	$24.1^{+7.5}_{-4.6}$	$2.83^{+0.47}_{-0.42}$	$0.02^{+0.22}_{-0.21}$	$0.94^{+0.43}_{-0.34}$	$0.19^{+0.08}_{-0.06}$	$26.7^{+7.2}_{-4.3}$	$0.34^{+0.13}_{-0.08}$	1800	$8.4^{+0.5}_{-0.7}$
GW200216_220804	81^{+20}_{-14}	$32.9^{+9.3}_{-8.5}$	51^{+22}_{-13}	30^{+14}_{-16}	$0.10^{+0.34}_{-0.36}$	$3.8^{+3.0}_{-2.0}$	$0.63^{+0.37}_{-0.29}$	78^{+19}_{-13}	$0.70^{+0.14}_{-0.24}$	2900	$8.1^{+0.4}_{-0.5}$
GW200219_094415	$65.0^{+12.6}_{-8.2}$	$27.6^{+5.6}_{-3.8}$	$37.5^{+10.1}_{-6.9}$	$27.9^{+7.4}_{-8.4}$	$-0.08^{+0.23}_{-0.29}$	$3.4^{+1.7}_{-1.5}$	$0.57^{+0.22}_{-0.22}$	$62.2^{+11.7}_{-7.8}$	$0.66^{+0.10}_{-0.13}$	700	$10.7^{+0.3}_{-0.5}$
GW200220_061928	148^{+55}_{-33}	62^{+23}_{-15}	87^{+40}_{-23}	61^{+26}_{-25}	$0.06^{+0.40}_{-0.38}$	$6.0^{+4.8}_{-3.1}$	$0.90^{+0.55}_{-0.40}$	141^{+51}_{-31}	$0.71^{+0.15}_{-0.17}$	3000	$7.2^{+0.4}_{-0.7}$
GW200220_124850	67^{+17}_{-12}	$28.2^{+7.3}_{-5.1}$	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$-0.07^{+0.27}_{-0.33}$	$4.0^{+2.8}_{-2.2}$	$0.66^{+0.36}_{-0.31}$	64^{+16}_{-11}	$0.67^{+0.11}_{-0.14}$	3200	$8.5^{+0.3}_{-0.5}$
GW200224_222234	$72.2^{+7.2}_{-5.1}$	$31.1^{+3.2}_{-2.6}$	$40.0^{+6.9}_{-4.5}$	$32.5^{+5.0}_{-7.2}$	$0.10^{+0.15}_{-0.15}$	$1.71^{+0.49}_{-0.64}$	$0.32^{+0.08}_{-0.11}$	$68.6^{+6.6}_{-4.7}$	$0.73^{+0.07}_{-0.07}$	50	$20.0^{+0.2}_{-0.2}$
GW200225_060421	$33.5^{+3.6}_{-3.0}$	$14.2^{+1.5}_{-1.4}$	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$-0.12^{+0.17}_{-0.28}$	$1.15^{+0.51}_{-0.53}$	$0.22^{+0.09}_{-0.10}$	$32.1^{+3.5}_{-2.8}$	$0.66^{+0.07}_{-0.13}$	370	$12.5^{+0.3}_{-0.4}$
GW200302_015811	$57.8^{+9.6}_{-6.9}$	$23.4^{+4.7}_{-3.0}$	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$0.01^{+0.25}_{-0.26}$	$1.48^{+1.02}_{-0.70}$	$0.28^{+0.16}_{-0.12}$	$55.5^{+8.9}_{-6.6}$	$0.66^{+0.13}_{-0.15}$	6000	$10.8^{+0.3}_{-0.4}$
GW200306_093714	$43.9^{+11.8}_{-7.5}$	$17.5^{+3.5}_{-3.0}$	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$0.32^{+0.28}_{-0.46}$	$2.1^{+1.7}_{-1.1}$	$0.38^{+0.24}_{-0.18}$	$41.7^{+12.3}_{-6.9}$	$0.78^{+0.11}_{-0.26}$	4600	$7.8^{+0.4}_{-0.6}$
GW200308_173609*	$50.6^{+10.9}_{-8.5}$	$19.0^{+4.8}_{-2.8}$	$36.4^{+11.2}_{-9.6}$	$13.8^{+7.2}_{-3.3}$	$0.65^{+0.17}_{-0.21}$	$5.4^{+2.7}_{-2.6}$	$0.83^{+0.32}_{-0.35}$	$47.4^{+11.1}_{-7.7}$	$0.91^{+0.03}_{-0.08}$	2000	$7.1^{+0.5}_{-0.5}$
GW200311_115853	$61.9^{+5.3}_{-4.2}$	$26.6^{+2.4}_{-2.0}$	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$-0.02^{+0.16}_{-0.20}$	$1.17^{+0.28}_{-0.40}$	$0.23^{+0.05}_{-0.07}$	$59.0^{+4.8}_{-3.9}$	$0.69^{+0.07}_{-0.08}$	35	$17.8^{+0.2}_{-0.2}$
GW200316_215756	$21.2^{+7.2}_{-2.0}$	$8.75^{+0.62}_{-0.55}$	$13.1^{+10.2}_{-2.9}$	$7.8^{+1.9}_{-2.9}$	$0.13^{+0.27}_{-0.10}$	$1.12^{+0.47}_{-0.44}$	$0.22^{+0.08}_{-0.08}$	$20.2^{+7.4}_{-1.9}$	$0.70^{+0.04}_{-0.04}$	190	$10.3^{+0.4}_{-0.4}$
GW200322_091133*	55^{+37}_{-27}	$15.5^{+15.7}_{-3.7}$	34^{+48}_{-18}	$14.0^{+16.8}_{-8.7}$	$0.24^{+0.45}_{-0.51}$	$3.6^{+7.0}_{-2.0}$	$0.60^{+0.84}_{-0.30}$	53^{+38}_{-26}	$0.78^{+0.16}_{-0.17}$	6500	$6.0^{+1.7}_{-1.2}$

In the NS/BH mass gap like [GW190814](#) in O3a

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW200202_154313	$17.58^{+1.78}_{-0.67}$	$7.49^{+0.24}_{-0.20}$	$10.1^{+3.5}_{-1.4}$	$7.3^{+1.1}_{-1.7}$	$0.04^{+0.13}_{-0.06}$	$0.41^{+0.15}_{-0.16}$	$0.09^{+0.03}_{-0.03}$	$16.76^{+1.87}_{-0.66}$	$0.69^{+0.03}_{-0.04}$	170	$10.8^{+0.2}_{-0.4}$
GW200208_130117	$65.4^{+7.8}_{-6.8}$	$27.7^{+3.6}_{-3.1}$	$37.8^{+9.2}_{-6.2}$	$27.4^{+6.1}_{-7.4}$	$-0.07^{+0.22}_{-0.27}$	$2.23^{+1.00}_{-0.85}$	$0.40^{+0.15}_{-0.14}$	$62.5^{+7.3}_{-6.4}$	$0.66^{+0.09}_{-0.13}$	30	$10.8^{+0.3}_{-0.4}$
GW200208_222617	63^{+100}_{-25}	$19.6^{+10.7}_{-5.1}$	51^{+104}_{-30}	$12.3^{+9.0}_{-5.7}$	$0.45^{+0.43}_{-0.44}$	$4.1^{+4.4}_{-1.9}$	$0.66^{+0.54}_{-0.28}$	61^{+100}_{-25}	$0.83^{+0.14}_{-0.27}$	2000	$7.4^{+1.4}_{-1.2}$
GW200209_085452	$62.6^{+13.9}_{-9.4}$	$26.7^{+6.0}_{-4.2}$	$35.6^{+10.5}_{-6.8}$	$27.1^{+7.8}_{-7.8}$	$-0.12^{+0.24}_{-0.30}$	$3.4^{+1.9}_{-1.8}$	$0.57^{+0.25}_{-0.26}$	$59.9^{+13.1}_{-8.9}$	$0.66^{+0.10}_{-0.12}$	730	$9.6^{+0.4}_{-0.5}$
GW200210_092254	$27.0^{+7.1}_{-4.3}$	$6.56^{+0.38}_{-0.40}$	$24.1^{+7.5}_{-4.6}$	$2.83^{+0.47}_{-0.42}$	$0.02^{+0.22}_{-0.21}$	$0.94^{+0.43}_{-0.34}$	$0.19^{+0.08}_{-0.06}$	$26.7^{+7.2}_{-4.3}$	$0.34^{+0.13}_{-0.08}$	1800	$8.4^{+0.5}_{-0.7}$
GW200216_220804	81^{+20}_{-14}	$32.9^{+9.3}_{-8.5}$	51^{+22}_{-13}	30^{+14}_{-16}	$0.10^{+0.34}_{-0.36}$	$3.8^{+3.0}_{-2.0}$	$0.63^{+0.37}_{-0.29}$	78^{+19}_{-13}	$0.70^{+0.14}_{-0.24}$	2900	$8.1^{+0.4}_{-0.5}$
GW200219_094415	$65.0^{+12.6}_{-8.2}$	$27.6^{+5.6}_{-3.8}$	$37.5^{+10.1}_{-6.9}$	$27.9^{+7.4}_{-8.4}$	$-0.08^{+0.23}_{-0.29}$	$3.4^{+1.7}_{-1.5}$	$0.57^{+0.22}_{-0.22}$	$62.2^{+11.7}_{-7.8}$	$0.66^{+0.10}_{-0.13}$	700	$10.7^{+0.3}_{-0.5}$
GW200220_061928	148^{+55}_{-33}	62^{+23}_{-15}	87^{+40}_{-23}	61^{+26}_{-25}	$0.06^{+0.40}_{-0.38}$	$6.0^{+4.8}_{-3.1}$	$0.90^{+0.55}_{-0.40}$	141^{+51}_{-31}	$0.71^{+0.15}_{-0.17}$	3000	$7.2^{+0.4}_{-0.7}$
GW200220_124850	67^{+17}_{-12}	$28.2^{+7.3}_{-5.1}$	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$-0.07^{+0.27}_{-0.33}$	$4.0^{+2.8}_{-2.2}$	$0.66^{+0.36}_{-0.31}$	64^{+16}_{-11}	$0.67^{+0.11}_{-0.14}$	3200	$8.5^{+0.3}_{-0.5}$
GW200224_222234	$72.2^{+7.2}_{-5.1}$	$31.1^{+3.2}_{-2.6}$	$40.0^{+6.9}_{-4.5}$	$32.5^{+5.0}_{-7.2}$	$0.10^{+0.15}_{-0.15}$	$1.71^{+0.49}_{-0.64}$	$0.32^{+0.08}_{-0.11}$	$68.6^{+6.6}_{-4.7}$	$0.73^{+0.07}_{-0.07}$	50	$20.0^{+0.2}_{-0.2}$
GW200225_060421	$33.5^{+3.6}_{-3.0}$	$14.2^{+1.5}_{-1.4}$	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$-0.12^{+0.17}_{-0.28}$	$1.15^{+0.51}_{-0.53}$	$0.22^{+0.09}_{-0.10}$	$32.1^{+3.5}_{-2.8}$	$0.66^{+0.07}_{-0.13}$	370	$12.5^{+0.3}_{-0.4}$
GW200302_015811	$57.8^{+9.6}_{-6.9}$	$23.4^{+4.7}_{-3.0}$	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$0.01^{+0.25}_{-0.26}$	$1.48^{+1.02}_{-0.70}$	$0.28^{+0.16}_{-0.12}$	$55.5^{+8.9}_{-6.6}$	$0.66^{+0.13}_{-0.15}$	6000	$10.8^{+0.3}_{-0.4}$
GW200306_093714	$43.9^{+11.8}_{-7.5}$	$17.5^{+3.5}_{-3.0}$	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$0.32^{+0.28}_{-0.46}$	$2.1^{+1.7}_{-1.1}$	$0.38^{+0.24}_{-0.18}$	$41.7^{+12.3}_{-6.9}$	$0.78^{+0.11}_{-0.26}$	4600	$7.8^{+0.4}_{-0.6}$
GW200308_173609*	$50.6^{+10.9}_{-8.5}$	$19.0^{+4.8}_{-2.8}$	$36.4^{+11.2}_{-9.6}$	$13.8^{+7.2}_{-3.3}$	$0.65^{+0.17}_{-0.21}$	$5.4^{+2.7}_{-2.6}$	$0.83^{+0.32}_{-0.35}$	$47.4^{+11.1}_{-7.7}$	$0.91^{+0.03}_{-0.08}$	2000	$7.1^{+0.5}_{-0.5}$
GW200311_115853	$61.9^{+5.3}_{-4.2}$	$26.6^{+2.4}_{-2.0}$	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$-0.02^{+0.16}_{-0.20}$	$1.17^{+0.28}_{-0.40}$	$0.23^{+0.05}_{-0.07}$	$59.0^{+4.8}_{-3.9}$	$0.69^{+0.07}_{-0.08}$	35	$17.8^{+0.2}_{-0.2}$
GW200316_215756	$21.2^{+7.2}_{-2.0}$	$8.75^{+0.62}_{-0.55}$	$13.1^{+10.2}_{-2.9}$	$7.8^{+1.9}_{-2.9}$	$0.13^{+0.27}_{-0.10}$	$1.12^{+0.47}_{-0.44}$	$0.22^{+0.08}_{-0.08}$	$20.2^{+7.4}_{-1.9}$	$0.70^{+0.04}_{-0.04}$	190	$10.3^{+0.4}_{-0.7}$
GW200322_091133*	55^{+37}_{-27}	$15.5^{+15.7}_{-3.7}$	34^{+48}_{-18}	$14.0^{+16.8}_{-8.7}$	$0.24^{+0.45}_{-0.51}$	$3.6^{+7.0}_{-2.0}$	$0.60^{+0.84}_{-0.30}$	53^{+38}_{-26}	$0.78^{+0.16}_{-0.17}$	6500	$6.0^{+1.7}_{-1.2}$

Most massive in O3b (less than [GW190521](#) and [GW190426_190642](#) in O3a).

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	$20.0^{+3.7}_{-1.8}$	$8.34^{+0.66}_{-0.57}$	$11.8^{+6.2}_{-2.2}$	$7.9^{+1.7}_{-2.4}$	$0.21^{+0.16}_{-0.10}$	$0.99^{+0.50}_{-0.47}$	$0.20^{+0.09}_{-0.09}$	$19.0^{+3.8}_{-1.7}$	$0.75^{+0.06}_{-0.05}$	2500	$8.9^{+0.3}_{-0.5}$
GW191105_143521	$18.5^{+2.1}_{-1.3}$	$7.82^{+0.61}_{-0.45}$	$10.7^{+3.7}_{-1.6}$	$7.7^{+1.4}_{-1.9}$	$-0.02^{+0.13}_{-0.09}$	$1.15^{+0.43}_{-0.48}$	$0.23^{+0.07}_{-0.09}$	$17.6^{+2.1}_{-1.2}$	$0.67^{+0.04}_{-0.05}$	640	$9.7^{+0.3}_{-0.5}$
GW191109_010717	112^{+20}_{-16}	$47.5^{+9.6}_{-7.5}$	65^{+11}_{-11}	47^{+15}_{-13}	$-0.29^{+0.42}_{-0.31}$	$1.29^{+1.13}_{-0.65}$	$0.25^{+0.18}_{-0.12}$	107^{+18}_{-15}	$0.61^{+0.18}_{-0.19}$	1600	$17.3^{+0.5}_{-0.5}$
GW191113_071753	$34.5^{+10.5}_{-9.8}$	$10.7^{+1.1}_{-1.0}$	29^{+12}_{-14}	$5.9^{+4.4}_{-1.3}$	$0.00^{+0.37}_{-0.29}$	$1.37^{+1.15}_{-0.62}$	$0.26^{+0.18}_{-0.11}$	34^{+11}_{-10}	$0.45^{+0.33}_{-0.11}$	3600	$7.9^{+0.5}_{-1.1}$
GW191126_115259	$20.7^{+3.4}_{-2.0}$	$8.65^{+0.95}_{-0.71}$	$12.1^{+5.5}_{-2.2}$	$8.3^{+1.9}_{-2.4}$	$0.21^{+0.15}_{-0.11}$	$1.62^{+0.74}_{-0.74}$	$0.30^{+0.12}_{-0.13}$	$19.6^{+3.5}_{-2.0}$	$0.75^{+0.06}_{-0.05}$	1400	$8.3^{+0.2}_{-0.5}$
GW191127_050227	80^{+39}_{-22}	$29.9^{+11.7}_{-9.1}$	53^{+47}_{-20}	24^{+17}_{-14}	$0.18^{+0.34}_{-0.36}$	$3.4^{+3.1}_{-1.9}$	$0.57^{+0.40}_{-0.29}$	76^{+39}_{-21}	$0.75^{+0.13}_{-0.29}$	980	$9.2^{+0.7}_{-0.6}$
GW191129_134029	$17.5^{+2.4}_{-1.2}$	$7.31^{+0.43}_{-0.28}$	$10.7^{+4.1}_{-2.1}$	$6.7^{+1.5}_{-1.7}$	$0.06^{+0.16}_{-0.18}$	$0.79^{+0.26}_{-0.33}$	$0.16^{+0.05}_{-0.06}$	$16.8^{+2.5}_{-1.2}$	$0.69^{+0.03}_{-0.05}$	850	$13.1^{+0.2}_{-0.3}$
GW191204_110529	$47.2^{+9.2}_{-8.0}$	$19.8^{+3.6}_{-3.3}$	$27.3^{+11.0}_{-6.0}$	$19.3^{+5.6}_{-6.0}$	$0.05^{+0.26}_{-0.27}$	$1.8^{+1.7}_{-1.1}$	$0.34^{+0.25}_{-0.18}$	$45.0^{+8.6}_{-7.6}$	$0.71^{+0.12}_{-0.11}$	3700	$8.8^{+0.4}_{-0.6}$
GW191204_171526	$20.21^{+1.70}_{-0.96}$	$8.55^{+0.38}_{-0.27}$	$11.9^{+3.3}_{-1.8}$	$8.2^{+1.4}_{-1.6}$	$0.16^{+0.08}_{-0.05}$	$0.65^{+0.19}_{-0.25}$	$0.13^{+0.04}_{-0.05}$	$19.21^{+1.79}_{-0.95}$	$0.73^{+0.03}_{-0.03}$	350	$17.5^{+0.2}_{-0.2}$
GW191215_223052	$43.3^{+5.3}_{-4.3}$	$18.4^{+2.2}_{-1.7}$	$24.9^{+7.1}_{-4.1}$	$18.1^{+3.8}_{-4.1}$	$-0.04^{+0.17}_{-0.21}$	$1.93^{+0.89}_{-0.86}$	$0.35^{+0.13}_{-0.14}$	$41.4^{+5.1}_{-4.1}$	$0.68^{+0.07}_{-0.07}$	530	$11.2^{+0.3}_{-0.4}$
GW191216_213338	$19.81^{+2.69}_{-0.94}$	$8.33^{+0.22}_{-0.19}$	$12.1^{+4.6}_{-2.3}$	$7.7^{+1.6}_{-1.9}$	$0.11^{+0.13}_{-0.06}$	$0.34^{+0.12}_{-0.13}$	$0.07^{+0.02}_{-0.03}$	$18.87^{+2.80}_{-0.94}$	$0.70^{+0.03}_{-0.04}$	490	$18.6^{+0.2}_{-0.2}$
<i>GW191219_163120</i>	$32.3^{+2.2}_{-2.7}$	$4.32^{+0.12}_{-0.17}$	$31.1^{+2.2}_{-2.8}$	$1.17^{+0.07}_{-0.06}$	$0.00^{+0.07}_{-0.09}$	$0.55^{+0.25}_{-0.16}$	$0.11^{+0.05}_{-0.03}$	$32.2^{+2.2}_{-2.7}$	$0.14^{+0.06}_{-0.06}$	1500	$9.1^{+0.5}_{-0.8}$
GW191222_033537	79^{+16}_{-11}	$33.8^{+7.1}_{-5.0}$	$45.1^{+10.9}_{-8.0}$	$34.7^{+9.3}_{-10.5}$	$-0.04^{+0.20}_{-0.25}$	$3.0^{+1.7}_{-1.7}$	$0.51^{+0.23}_{-0.26}$	$75.5^{+15.3}_{-9.9}$	$0.67^{+0.08}_{-0.11}$	2000	$12.5^{+0.2}_{-0.3}$
GW191230_180458	86^{+19}_{-12}	$36.5^{+8.2}_{-5.6}$	$49.4^{+14.0}_{-9.6}$	37^{+11}_{-12}	$-0.05^{+0.26}_{-0.31}$	$4.3^{+2.1}_{-1.9}$	$0.69^{+0.26}_{-0.27}$	82^{+17}_{-11}	$0.68^{+0.11}_{-0.13}$	1100	$10.4^{+0.3}_{-0.4}$
<i>GW200105_162426</i>	$11.0^{+1.5}_{-1.4}$	$3.42^{+0.08}_{-0.08}$	$9.0^{+1.7}_{-1.7}$	$1.91^{+0.33}_{-0.24}$	$0.00^{+0.13}_{-0.18}$	$0.27^{+0.12}_{-0.11}$	$0.06^{+0.02}_{-0.02}$	$10.7^{+1.5}_{-1.4}$	$0.43^{+0.05}_{-0.02}$	7900	$13.7^{+0.2}_{-0.4}$
GW200112_155838	$63.9^{+5.7}_{-4.6}$	$27.4^{+2.6}_{-2.1}$	$35.6^{+6.7}_{-4.5}$	$28.3^{+4.4}_{-5.9}$	$0.06^{+0.15}_{-0.15}$	$1.25^{+0.43}_{-0.46}$	$0.24^{+0.07}_{-0.08}$	$60.8^{+5.3}_{-4.3}$	$0.71^{+0.06}_{-0.06}$	4300	$19.8^{+0.1}_{-0.2}$
GW200115_042309	$7.4^{+1.8}_{-1.7}$	$2.43^{+0.05}_{-0.07}$	$5.9^{+2.0}_{-2.5}$	$1.44^{+0.85}_{-0.29}$	$-0.15^{+0.24}_{-0.42}$	$0.29^{+0.15}_{-0.10}$	$0.06^{+0.03}_{-0.02}$	$7.2^{+1.8}_{-1.7}$	$0.42^{+0.09}_{-0.05}$	370	$11.3^{+0.3}_{-0.5}$
GW200128_022011	75^{+17}_{-12}	$32.0^{+7.5}_{-5.5}$	$42.2^{+11.6}_{-8.1}$	$32.6^{+9.5}_{-9.2}$	$0.12^{+0.24}_{-0.25}$	$3.4^{+2.1}_{-1.8}$	$0.56^{+0.28}_{-0.28}$	71^{+16}_{-11}	$0.74^{+0.10}_{-0.10}$	2600	$10.6^{+0.3}_{-0.4}$
GW200129_065458	$63.4^{+4.3}_{-3.6}$	$27.2^{+2.1}_{-2.3}$	$34.5^{+9.9}_{-3.2}$	$28.9^{+3.4}_{-9.3}$	$0.11^{+0.11}_{-0.16}$	$0.90^{+0.29}_{-0.38}$	$0.18^{+0.05}_{-0.07}$	$60.3^{+4.0}_{-3.3}$	$0.73^{+0.06}_{-0.05}$	130	$26.8^{+0.2}_{-0.2}$

Smallest total mass for a BBH

Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	$20.0^{+3.7}_{-1.8}$	$8.34^{+0.66}_{-0.57}$	$11.8^{+6.2}_{-2.2}$	$7.9^{+1.7}_{-2.4}$	$0.21^{+0.16}_{-0.10}$	$0.99^{+0.50}_{-0.47}$	$0.20^{+0.09}_{-0.09}$	$19.0^{+3.8}_{-1.7}$	$0.75^{+0.06}_{-0.05}$	2500	$8.9^{+0.3}_{-0.5}$
GW191105_143521	$18.5^{+2.1}_{-1.3}$	$7.82^{+0.61}_{-0.45}$	$10.7^{+3.7}_{-1.6}$	$7.7^{+1.4}_{-1.9}$	$-0.02^{+0.13}_{-0.09}$	$1.15^{+0.43}_{-0.48}$	$0.23^{+0.07}_{-0.09}$	$17.6^{+2.1}_{-1.2}$	$0.67^{+0.04}_{-0.05}$	640	$9.7^{+0.3}_{-0.5}$
GW191109_010717	112^{+20}_{-16}	$47.5^{+9.6}_{-7.5}$	65^{+11}_{-11}	47^{+15}_{-13}	$-0.29^{+0.42}_{-0.31}$	$1.29^{+1.13}_{-0.65}$	$0.25^{+0.18}_{-0.12}$	107^{+18}_{-15}	$0.61^{+0.18}_{-0.19}$	1600	$17.3^{+0.5}_{-0.5}$
GW191113_071753	$34.5^{+10.5}_{-9.8}$	$10.7^{+1.1}_{-1.0}$	29^{+12}_{-14}	$5.9^{+4.4}_{-1.3}$	$0.00^{+0.37}_{-0.29}$	$1.37^{+1.15}_{-0.62}$	$0.26^{+0.18}_{-0.11}$	34^{+11}_{-10}	$0.45^{+0.33}_{-0.11}$	3600	$7.9^{+0.5}_{-1.1}$
GW191126_115259	$20.7^{+3.4}_{-2.0}$	$8.65^{+0.95}_{-0.71}$	$12.1^{+5.5}_{-2.2}$	$8.3^{+1.9}_{-2.4}$	$0.21^{+0.15}_{-0.11}$	$1.62^{+0.74}_{-0.74}$	$0.30^{+0.12}_{-0.13}$	$19.6^{+3.5}_{-2.0}$	$0.75^{+0.06}_{-0.05}$	1400	$8.3^{+0.2}_{-0.5}$
GW191127_050227	80^{+39}_{-22}	$29.9^{+11.7}_{-9.1}$	53^{+47}_{-20}	24^{+17}_{-14}	$0.18^{+0.34}_{-0.36}$	$3.4^{+3.1}_{-1.9}$	$0.57^{+0.40}_{-0.29}$	76^{+39}_{-21}	$0.75^{+0.13}_{-0.29}$	980	$9.2^{+0.7}_{-0.6}$
GW191129_134029	$17.5^{+2.4}_{-1.2}$	$7.31^{+0.43}_{-0.28}$	$10.7^{+4.1}_{-2.1}$	$6.7^{+1.5}_{-1.7}$	$0.06^{+0.16}_{-0.08}$	$0.79^{+0.26}_{-0.33}$	$0.16^{+0.05}_{-0.06}$	$16.8^{+2.5}_{-1.2}$	$0.69^{+0.03}_{-0.05}$	850	$13.1^{+0.2}_{-0.3}$
GW191204_110529	$47.2^{+9.2}_{-8.0}$	$19.8^{+3.6}_{-3.3}$	$27.3^{+11.0}_{-6.0}$	$19.3^{+5.6}_{-6.0}$	$0.05^{+0.26}_{-0.27}$	$1.8^{+1.7}_{-1.1}$	$0.34^{+0.25}_{-0.18}$	$45.0^{+8.6}_{-7.6}$	$0.71^{+0.12}_{-0.11}$	3700	$8.8^{+0.4}_{-0.6}$
GW191204_171526	$20.21^{+1.70}_{-0.96}$	$8.55^{+0.38}_{-0.27}$	$11.9^{+3.3}_{-1.8}$	$8.2^{+1.4}_{-1.6}$	$0.16^{+0.08}_{-0.05}$	$0.65^{+0.19}_{-0.25}$	$0.13^{+0.04}_{-0.05}$	$19.21^{+1.79}_{-0.95}$	$0.73^{+0.03}_{-0.03}$	350	$17.5^{+0.2}_{-0.2}$
GW191215_223052	$43.3^{+5.3}_{-4.3}$	$18.4^{+2.2}_{-1.7}$	$24.9^{+7.1}_{-4.1}$	$18.1^{+3.8}_{-4.1}$	$-0.04^{+0.17}_{-0.21}$	$1.93^{+0.89}_{-0.86}$	$0.35^{+0.13}_{-0.14}$	$41.4^{+5.1}_{-4.1}$	$0.68^{+0.07}_{-0.07}$	530	$11.2^{+0.3}_{-0.4}$
GW191216_213338	$19.81^{+2.69}_{-0.94}$	$8.33^{+0.22}_{-0.19}$	$12.1^{+4.6}_{-2.3}$	$7.7^{+1.6}_{-1.9}$	$0.11^{+0.13}_{-0.06}$	$0.34^{+0.12}_{-0.13}$	$0.07^{+0.02}_{-0.03}$	$18.87^{+2.80}_{-0.94}$	$0.70^{+0.03}_{-0.04}$	490	$18.6^{+0.2}_{-0.2}$
<i>GW191219_163120</i>	$32.3^{+2.2}_{-2.7}$	$4.32^{+0.12}_{-0.17}$	$31.1^{+2.2}_{-2.8}$	$1.17^{+0.07}_{-0.06}$	$0.00^{+0.07}_{-0.09}$	$0.55^{+0.25}_{-0.16}$	$0.11^{+0.05}_{-0.03}$	$32.2^{+2.2}_{-2.7}$	$0.14^{+0.06}_{-0.06}$	1500	$9.1^{+0.5}_{-0.8}$
GW191222_033537	79^{+16}_{-11}	$33.8^{+7.1}_{-5.0}$	$45.1^{+10.9}_{-8.0}$	$34.7^{+9.3}_{-10.5}$	$-0.04^{+0.20}_{-0.25}$	$3.0^{+1.7}_{-1.7}$	$0.51^{+0.23}_{-0.26}$	$75.5^{+15.3}_{-9.9}$	$0.67^{+0.08}_{-0.11}$	2000	$12.5^{+0.2}_{-0.3}$
GW191230_180458	86^{+19}_{-12}	$36.5^{+8.2}_{-5.6}$	$49.4^{+14.0}_{-9.6}$	37^{+11}_{-12}	$-0.05^{+0.26}_{-0.31}$	$4.3^{+2.1}_{-1.9}$	$0.69^{+0.26}_{-0.27}$	82^{+17}_{-11}	$0.68^{+0.11}_{-0.13}$	1100	$10.4^{+0.3}_{-0.4}$
<i>GW200105_162426</i>	$11.0^{+1.5}_{-1.4}$	$3.42^{+0.08}_{-0.08}$	$9.0^{+1.7}_{-1.7}$	$1.91^{+0.33}_{-0.24}$	$0.00^{+0.13}_{-0.18}$	$0.27^{+0.12}_{-0.11}$	$0.06^{+0.02}_{-0.02}$	$10.7^{+1.5}_{-1.4}$	$0.43^{+0.05}_{-0.02}$	7900	$13.7^{+0.2}_{-0.4}$
GW200112_155838	$63.9^{+5.7}_{-4.6}$	$27.4^{+2.6}_{-2.1}$	$35.6^{+6.7}_{-4.5}$	$28.3^{+4.4}_{-5.9}$	$0.06^{+0.15}_{-0.15}$	$1.25^{+0.43}_{-0.46}$	$0.24^{+0.07}_{-0.08}$	$60.8^{+5.3}_{-4.3}$	$0.71^{+0.06}_{-0.06}$	4300	$19.8^{+0.1}_{-0.2}$
GW200115_042309	$7.4^{+1.8}_{-1.7}$	$2.43^{+0.05}_{-0.07}$	$5.9^{+2.0}_{-2.5}$	$1.44^{+0.85}_{-0.29}$	$-0.15^{+0.24}_{-0.42}$	$0.29^{+0.15}_{-0.10}$	$0.06^{+0.03}_{-0.02}$	$7.2^{+1.8}_{-1.7}$	$0.42^{+0.09}_{-0.05}$	370	$11.3^{+0.3}_{-0.5}$
GW200128_022011	75^{+17}_{-12}	$32.0^{+7.5}_{-5.5}$	$42.2^{+11.6}_{-8.1}$	$32.6^{+9.5}_{-9.2}$	$0.12^{+0.24}_{-0.25}$	$3.4^{+2.1}_{-1.8}$	$0.56^{+0.28}_{-0.28}$	71^{+16}_{-11}	$0.74^{+0.10}_{-0.10}$	2600	$10.6^{+0.3}_{-0.4}$
GW200129_065458	$63.4^{+4.3}_{-3.6}$	$27.2^{+2.1}_{-2.3}$	$34.5^{+9.9}_{-3.2}$	$28.9^{+3.4}_{-9.3}$	$0.11^{+0.11}_{-0.16}$	$0.90^{+0.29}_{-0.38}$	$0.18^{+0.05}_{-0.07}$	$60.3^{+4.0}_{-3.3}$	$0.73^{+0.06}_{-0.05}$	130	$26.8^{+0.2}_{-0.2}$

Confident positive effective spin

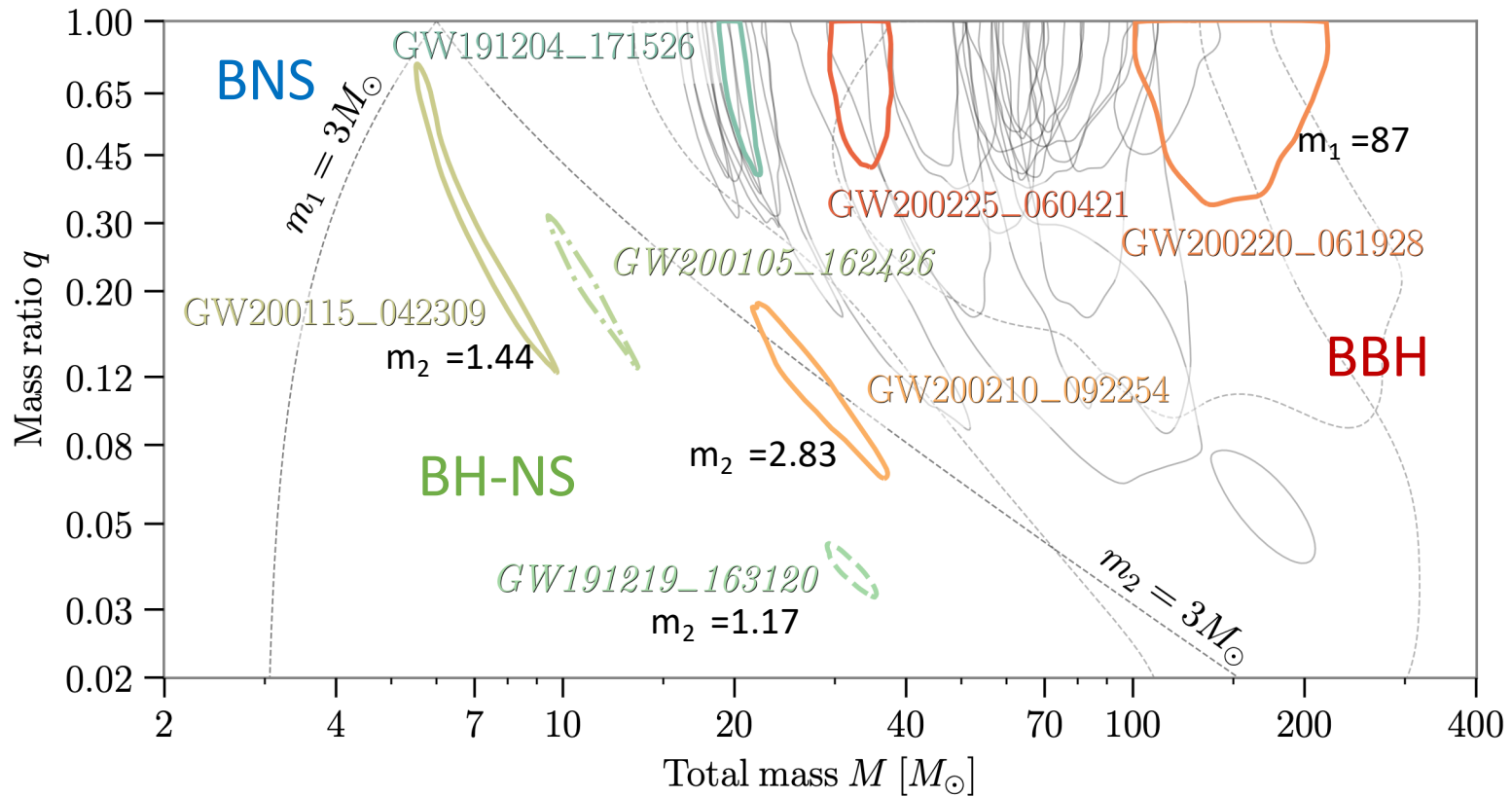
Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg ²)	SNR
GW191103_012549	$20.0^{+3.7}_{-1.8}$	$8.34^{+0.66}_{-0.57}$	$11.8^{+6.2}_{-2.2}$	$7.9^{+1.7}_{-2.4}$	$0.21^{+0.16}_{-0.10}$	$0.99^{+0.50}_{-0.47}$	$0.20^{+0.09}_{-0.09}$	$19.0^{+3.8}_{-1.7}$	$0.75^{+0.06}_{-0.05}$	2500	$8.9^{+0.3}_{-0.5}$
GW191105_143521	$18.5^{+2.1}_{-1.3}$	$7.82^{+0.61}_{-0.45}$	$10.7^{+3.7}_{-1.6}$	$7.7^{+1.4}_{-1.9}$	$-0.02^{+0.13}_{-0.09}$	$1.15^{+0.43}_{-0.48}$	$0.23^{+0.07}_{-0.09}$	$17.6^{+2.1}_{-1.2}$	$0.67^{+0.04}_{-0.05}$	640	$9.7^{+0.3}_{-0.5}$
GW191109_010717	112^{+20}_{-16}	$47.5^{+9.6}_{-7.5}$	65^{+11}_{-11}	47^{+15}_{-13}	$-0.29^{+0.42}_{-0.31}$	$1.29^{+1.13}_{-0.65}$	$0.25^{+0.18}_{-0.12}$	107^{+18}_{-15}	$0.61^{+0.18}_{-0.19}$	1600	$17.3^{+0.5}_{-0.5}$
GW191113_071753	$34.5^{+10.5}_{-9.8}$	$10.7^{+1.1}_{-1.0}$	29^{+12}_{-14}	$5.9^{+4.4}_{-1.3}$	$0.00^{+0.37}_{-0.29}$	$1.37^{+1.15}_{-0.62}$	$0.26^{+0.18}_{-0.11}$	34^{+11}_{-10}	$0.45^{+0.33}_{-0.11}$	3600	$7.9^{+0.5}_{-1.1}$
GW191126_115259	$20.7^{+3.4}_{-2.0}$	$8.65^{+0.95}_{-0.71}$	$12.1^{+5.5}_{-2.2}$	$8.3^{+1.9}_{-2.4}$	$0.21^{+0.15}_{-0.11}$	$1.62^{+0.74}_{-0.74}$	$0.30^{+0.12}_{-0.13}$	$19.6^{+3.5}_{-2.0}$	$0.75^{+0.06}_{-0.05}$	1400	$8.3^{+0.2}_{-0.5}$
GW191127_050227	80^{+39}_{-22}	$29.9^{+11.7}_{-9.1}$	53^{+47}_{-20}	24^{+17}_{-14}	$0.18^{+0.34}_{-0.36}$	$3.4^{+3.1}_{-1.9}$	$0.57^{+0.40}_{-0.29}$	76^{+39}_{-21}	$0.75^{+0.13}_{-0.29}$	980	$9.2^{+0.7}_{-0.6}$
GW191129_134029	$17.5^{+2.4}_{-1.2}$	$7.31^{+0.43}_{-0.28}$	$10.7^{+4.1}_{-2.1}$	$6.7^{+1.5}_{-1.7}$	$0.06^{+0.16}_{-0.08}$	$0.79^{+0.26}_{-0.33}$	$0.16^{+0.05}_{-0.06}$	$16.8^{+2.5}_{-1.2}$	$0.69^{+0.03}_{-0.05}$	850	$13.1^{+0.2}_{-0.3}$
GW191204_110529	$47.2^{+9.2}_{-8.0}$	$19.8^{+3.6}_{-3.3}$	$27.3^{+11.0}_{-6.0}$	$19.3^{+5.6}_{-6.0}$	$0.05^{+0.26}_{-0.27}$	$1.8^{+1.7}_{-1.1}$	$0.34^{+0.25}_{-0.18}$	$45.0^{+8.6}_{-7.6}$	$0.71^{+0.12}_{-0.11}$	3700	$8.8^{+0.4}_{-0.6}$
GW191204_171526	$20.21^{+1.70}_{-0.96}$	$8.55^{+0.38}_{-0.27}$	$11.9^{+3.3}_{-1.8}$	$8.2^{+1.4}_{-1.6}$	$0.16^{+0.08}_{-0.05}$	$0.65^{+0.19}_{-0.25}$	$0.13^{+0.04}_{-0.05}$	$19.21^{+1.79}_{-0.95}$	$0.73^{+0.03}_{-0.03}$	350	$17.5^{+0.2}_{-0.2}$
GW191215_223052	$43.3^{+5.3}_{-4.3}$	$18.4^{+2.2}_{-1.7}$	$24.9^{+7.1}_{-4.1}$	$18.1^{+3.8}_{-4.1}$	$-0.04^{+0.17}_{-0.21}$	$1.93^{+0.89}_{-0.86}$	$0.35^{+0.13}_{-0.14}$	$41.4^{+5.1}_{-4.1}$	$0.68^{+0.07}_{-0.07}$	530	$11.2^{+0.3}_{-0.4}$
GW191216_213338	$19.81^{+2.69}_{-0.94}$	$8.33^{+0.22}_{-0.19}$	$12.1^{+4.6}_{-2.3}$	$7.7^{+1.6}_{-1.9}$	$0.11^{+0.13}_{-0.06}$	$0.34^{+0.12}_{-0.13}$	$0.07^{+0.02}_{-0.03}$	$18.87^{+2.80}_{-0.94}$	$0.70^{+0.03}_{-0.04}$	490	$18.6^{+0.2}_{-0.2}$
<i>GW191219_163120</i>	$32.3^{+2.2}_{-2.7}$	$4.32^{+0.12}_{-0.17}$	$31.1^{+2.2}_{-2.8}$	$1.17^{+0.07}_{-0.06}$	$0.00^{+0.07}_{-0.09}$	$0.55^{+0.25}_{-0.16}$	$0.11^{+0.05}_{-0.03}$	$32.2^{+2.2}_{-2.7}$	$0.14^{+0.06}_{-0.06}$	1500	$9.1^{+0.5}_{-0.8}$
GW191222_033537	79^{+16}_{-11}	$33.8^{+7.1}_{-5.0}$	$45.1^{+10.9}_{-8.0}$	$34.7^{+9.3}_{-10.5}$	$-0.04^{+0.20}_{-0.25}$	$3.0^{+1.7}_{-1.7}$	$0.51^{+0.23}_{-0.26}$	$75.5^{+15.3}_{-9.9}$	$0.67^{+0.08}_{-0.11}$	2000	$12.5^{+0.2}_{-0.3}$
GW191230_180458	86^{+19}_{-12}	$36.5^{+8.2}_{-5.6}$	$49.4^{+14.0}_{-9.6}$	37^{+11}_{-12}	$-0.05^{+0.26}_{-0.31}$	$4.3^{+2.1}_{-1.9}$	$0.69^{+0.26}_{-0.27}$	82^{+17}_{-11}	$0.68^{+0.11}_{-0.13}$	1100	$10.4^{+0.3}_{-0.4}$
<i>GW200105_162426</i>	$11.0^{+1.5}_{-1.4}$	$3.42^{+0.08}_{-0.08}$	$9.0^{+1.7}_{-1.7}$	$1.91^{+0.33}_{-0.24}$	$0.00^{+0.13}_{-0.18}$	$0.27^{+0.12}_{-0.11}$	$0.06^{+0.02}_{-0.02}$	$10.7^{+1.5}_{-1.4}$	$0.43^{+0.05}_{-0.02}$	7900	$13.7^{+0.2}_{-0.4}$
GW200112_155838	$63.9^{+5.7}_{-4.6}$	$27.4^{+2.6}_{-2.1}$	$35.6^{+6.7}_{-4.5}$	$28.3^{+4.4}_{-5.9}$	$0.06^{+0.15}_{-0.15}$	$1.25^{+0.43}_{-0.46}$	$0.24^{+0.07}_{-0.08}$	$60.8^{+5.3}_{-4.3}$	$0.71^{+0.06}_{-0.06}$	4300	$19.8^{+0.1}_{-0.2}$
GW200115_042309	$7.4^{+1.8}_{-1.7}$	$2.43^{+0.05}_{-0.07}$	$5.9^{+2.0}_{-2.5}$	$1.44^{+0.85}_{-0.29}$	$-0.15^{+0.24}_{-0.42}$	$0.29^{+0.15}_{-0.10}$	$0.06^{+0.03}_{-0.02}$	$7.2^{+1.8}_{-1.7}$	$0.42^{+0.09}_{-0.05}$	370	$11.3^{+0.3}_{-0.5}$
GW200128_022011	75^{+17}_{-12}	$32.0^{+7.5}_{-5.5}$	$42.2^{+11.6}_{-8.1}$	$32.6^{+9.5}_{-9.2}$	$0.12^{+0.24}_{-0.25}$	$3.4^{+2.1}_{-1.8}$	$0.56^{+0.28}_{-0.28}$	71^{+16}_{-11}	$0.74^{+0.10}_{-0.10}$	2600	$10.6^{+0.3}_{-0.4}$
GW200129_065458	$63.4^{+4.3}_{-3.6}$	$27.2^{+2.1}_{-2.3}$	$34.5^{+9.9}_{-3.2}$	$28.9^{+3.4}_{-9.3}$	$0.11^{+0.11}_{-0.16}$	$0.90^{+0.29}_{-0.38}$	$0.18^{+0.05}_{-0.07}$	$60.3^{+4.0}_{-3.3}$	$0.73^{+0.06}_{-0.05}$	130	$26.8^{+0.2}_{-0.2}$

One of the most massive event of the catalog. Negative effective spin with 90% probability

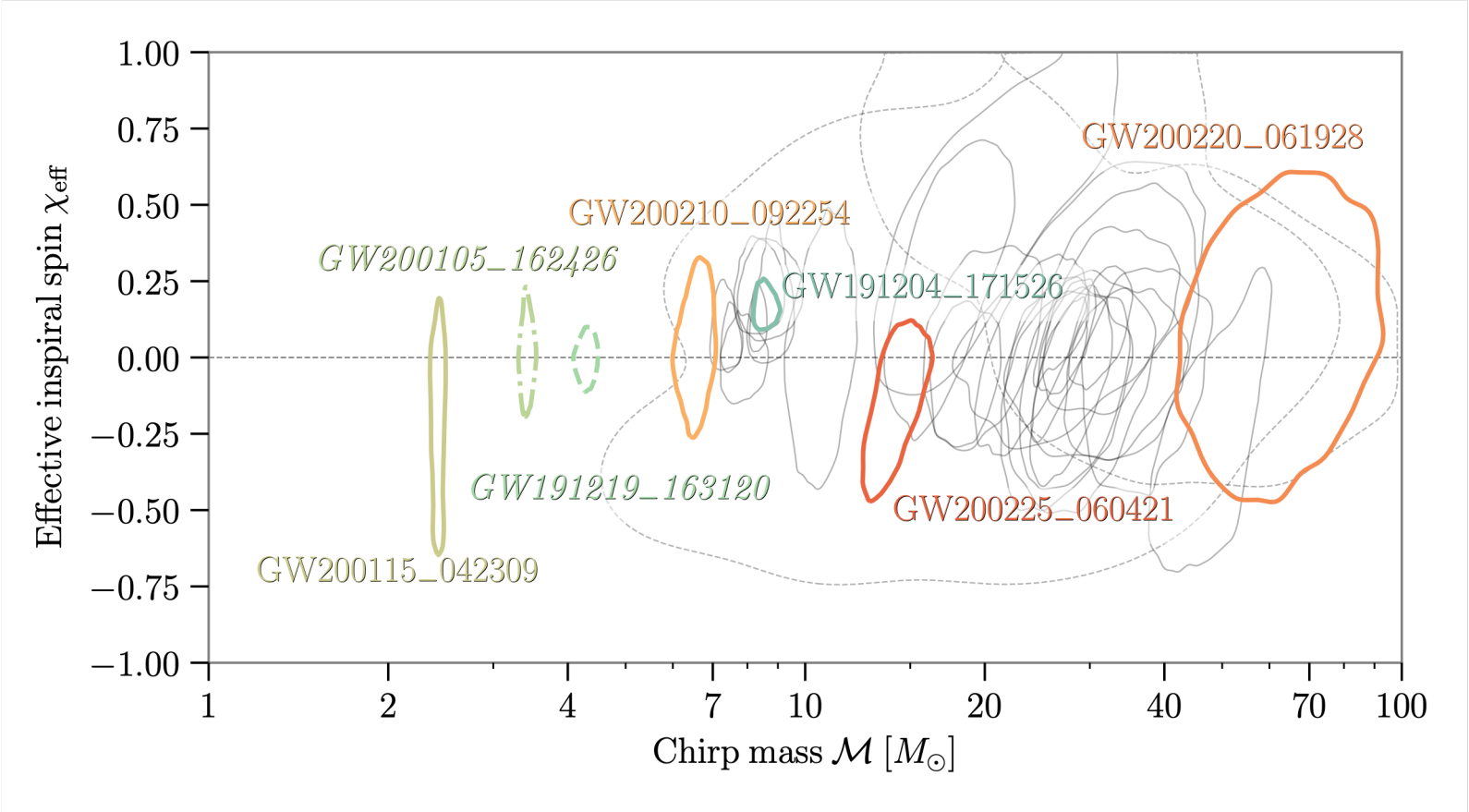
Event	M (M_{\odot})	\mathcal{M} (M_{\odot})	m_1 (M_{\odot})	m_2 (M_{\odot})	χ_{eff}	D_L (Gpc)	z	M_f (M_{\odot})	χ_f	$\Delta\Omega$ (deg 2)	SNR
GW200202_154313	$17.58^{+1.78}_{-0.67}$	$7.49^{+0.24}_{-0.20}$	$10.1^{+3.5}_{-1.4}$	$7.3^{+1.1}_{-1.7}$	$0.04^{+0.13}_{-0.06}$	$0.41^{+0.15}_{-0.16}$	$0.09^{+0.03}_{-0.03}$	$16.76^{+1.87}_{-0.66}$	$0.69^{+0.03}_{-0.04}$	170	$10.8^{+0.2}_{-0.4}$
GW200208_130117	$65.4^{+7.8}_{-6.8}$	$27.7^{+3.6}_{-3.1}$	$37.8^{+9.2}_{-6.2}$	$27.4^{+6.1}_{-7.4}$	$-0.07^{+0.22}_{-0.27}$	$2.23^{+1.00}_{-0.85}$	$0.40^{+0.15}_{-0.14}$	$62.5^{+7.3}_{-6.4}$	$0.66^{+0.09}_{-0.13}$	30	$10.8^{+0.3}_{-0.4}$
GW200208_222617	63^{+100}_{-25}	$19.6^{+10.7}_{-5.1}$	51^{+104}_{-30}	$12.3^{+9.0}_{-5.7}$	$0.45^{+0.43}_{-0.44}$	$4.1^{+4.4}_{-1.9}$	$0.66^{+0.54}_{-0.28}$	61^{+100}_{-25}	$0.83^{+0.14}_{-0.27}$	2000	$7.4^{+1.4}_{-1.2}$
GW200209_085452	$62.6^{+13.9}_{-9.4}$	$26.7^{+6.0}_{-4.2}$	$35.6^{+10.5}_{-6.8}$	$27.1^{+7.8}_{-7.8}$	$-0.12^{+0.24}_{-0.30}$	$3.4^{+1.9}_{-1.8}$	$0.57^{+0.25}_{-0.26}$	$59.9^{+13.1}_{-8.9}$	$0.66^{+0.10}_{-0.12}$	730	$9.6^{+0.4}_{-0.5}$
GW200210_092254	$27.0^{+7.1}_{-4.3}$	$6.56^{+0.38}_{-0.40}$	$24.1^{+7.5}_{-4.6}$	$2.83^{+0.47}_{-0.42}$	$0.02^{+0.22}_{-0.21}$	$0.94^{+0.43}_{-0.34}$	$0.19^{+0.08}_{-0.06}$	$26.7^{+7.2}_{-4.3}$	$0.34^{+0.13}_{-0.08}$	1800	$8.4^{+0.5}_{-0.7}$
GW200216_220804	81^{+20}_{-14}	$32.9^{+9.3}_{-8.5}$	51^{+22}_{-13}	30^{+14}_{-16}	$0.10^{+0.34}_{-0.36}$	$3.8^{+3.0}_{-2.0}$	$0.63^{+0.37}_{-0.29}$	78^{+19}_{-13}	$0.70^{+0.14}_{-0.24}$	2900	$8.1^{+0.4}_{-0.5}$
GW200219_094415	$65.0^{+12.6}_{-8.2}$	$27.6^{+5.6}_{-3.8}$	$37.5^{+10.1}_{-6.9}$	$27.9^{+7.4}_{-8.4}$	$-0.08^{+0.23}_{-0.29}$	$3.4^{+1.7}_{-1.5}$	$0.57^{+0.22}_{-0.22}$	$62.2^{+11.7}_{-7.8}$	$0.66^{+0.10}_{-0.13}$	700	$10.7^{+0.3}_{-0.5}$
GW200220_061928	148^{+55}_{-33}	62^{+23}_{-15}	87^{+40}_{-23}	61^{+25}_{-26}	$0.06^{+0.40}_{-0.38}$	$6.0^{+4.8}_{-3.1}$	$0.90^{+0.55}_{-0.40}$	141^{+51}_{-31}	$0.71^{+0.15}_{-0.17}$	3000	$7.2^{+0.4}_{-0.7}$
GW200220_124850	67^{+17}_{-12}	$28.2^{+7.3}_{-5.1}$	$38.9^{+14.1}_{-8.6}$	$27.9^{+9.2}_{-9.0}$	$-0.07^{+0.27}_{-0.33}$	$4.0^{+2.8}_{-2.2}$	$0.66^{+0.36}_{-0.31}$	64^{+16}_{-11}	$0.67^{+0.11}_{-0.14}$	3200	$8.5^{+0.3}_{-0.5}$
GW200224_222234	$72.2^{+7.2}_{-5.1}$	$31.1^{+3.2}_{-2.6}$	$40.0^{+6.9}_{-4.5}$	$32.5^{+5.0}_{-7.2}$	$0.10^{+0.15}_{-0.15}$	$1.71^{+0.49}_{-0.64}$	$0.32^{+0.08}_{-0.11}$	$68.6^{+6.6}_{-4.7}$	$0.73^{+0.07}_{-0.07}$	50	$20.0^{+0.2}_{-0.2}$
GW200225_060421	$33.5^{+3.6}_{-3.0}$	$14.2^{+1.5}_{-1.4}$	$19.3^{+5.0}_{-3.0}$	$14.0^{+2.8}_{-3.5}$	$-0.12^{+0.17}_{-0.28}$	$1.15^{+0.51}_{-0.53}$	$0.22^{+0.09}_{-0.10}$	$32.1^{+3.5}_{-2.8}$	$0.66^{+0.07}_{-0.13}$	370	$12.5^{+0.3}_{-0.4}$
GW200302_015811	$57.8^{+9.6}_{-6.9}$	$23.4^{+4.7}_{-3.0}$	$37.8^{+8.7}_{-8.5}$	$20.0^{+8.1}_{-5.7}$	$0.01^{+0.25}_{-0.26}$	$1.48^{+1.02}_{-0.70}$	$0.28^{+0.16}_{-0.12}$	$55.5^{+8.9}_{-6.6}$	$0.66^{+0.13}_{-0.15}$	6000	$10.8^{+0.3}_{-0.4}$
GW200306_093714	$43.9^{+11.8}_{-7.5}$	$17.5^{+3.5}_{-3.0}$	$28.3^{+17.1}_{-7.7}$	$14.8^{+6.5}_{-6.4}$	$0.32^{+0.28}_{-0.46}$	$2.1^{+1.7}_{-1.1}$	$0.38^{+0.24}_{-0.18}$	$41.7^{+12.3}_{-6.9}$	$0.78^{+0.11}_{-0.26}$	4600	$7.8^{+0.4}_{-0.6}$
GW200308_173609*	$50.6^{+10.9}_{-8.5}$	$19.0^{+4.8}_{-2.8}$	$36.4^{+11.2}_{-9.6}$	$13.8^{+7.2}_{-3.3}$	$0.65^{+0.17}_{-0.21}$	$5.4^{+2.7}_{-2.6}$	$0.83^{+0.32}_{-0.35}$	$47.4^{+11.1}_{-7.7}$	$0.91^{+0.03}_{-0.08}$	2000	$7.1^{+0.5}_{-0.5}$
GW200311_115853	$61.9^{+5.3}_{-4.2}$	$26.6^{+2.4}_{-2.0}$	$34.2^{+6.4}_{-3.8}$	$27.7^{+4.1}_{-5.9}$	$-0.02^{+0.16}_{-0.20}$	$1.17^{+0.28}_{-0.40}$	$0.23^{+0.05}_{-0.07}$	$59.0^{+4.8}_{-3.9}$	$0.69^{+0.07}_{-0.08}$	35	$17.8^{+0.2}_{-0.2}$
GW200316_215756	$21.2^{+7.2}_{-2.0}$	$8.75^{+0.62}_{-0.55}$	$13.1^{+10.2}_{-2.9}$	$7.8^{+1.9}_{-2.9}$	$0.13^{+0.27}_{-0.10}$	$1.12^{+0.47}_{-0.44}$	$0.22^{+0.08}_{-0.08}$	$20.2^{+7.4}_{-1.9}$	$0.70^{+0.04}_{-0.04}$	190	$10.3^{+0.4}_{-0.7}$
GW200322_091133*	55^{+37}_{-27}	$15.5^{+15.7}_{-3.7}$	34^{+48}_{-18}	$14.0^{+16.8}_{-8.7}$	$0.24^{+0.45}_{-0.51}$	$3.6^{+7.0}_{-2.0}$	$0.60^{+0.84}_{-0.30}$	53^{+38}_{-26}	$0.78^{+0.16}_{-0.17}$	6500	$6.0^{+1.7}_{-1.2}$

Most massive in O3b (less than [GW190521](#) and [GW190426_190642](#) in O3a).

The masses



The spins



Astrophysical implications

We use a reduced sample of 67 events with higher significance out of which one may not be astrophysical for combined population studies and a sample of 76 events out of which 4-5 may not be astrophysical for BBH studies.

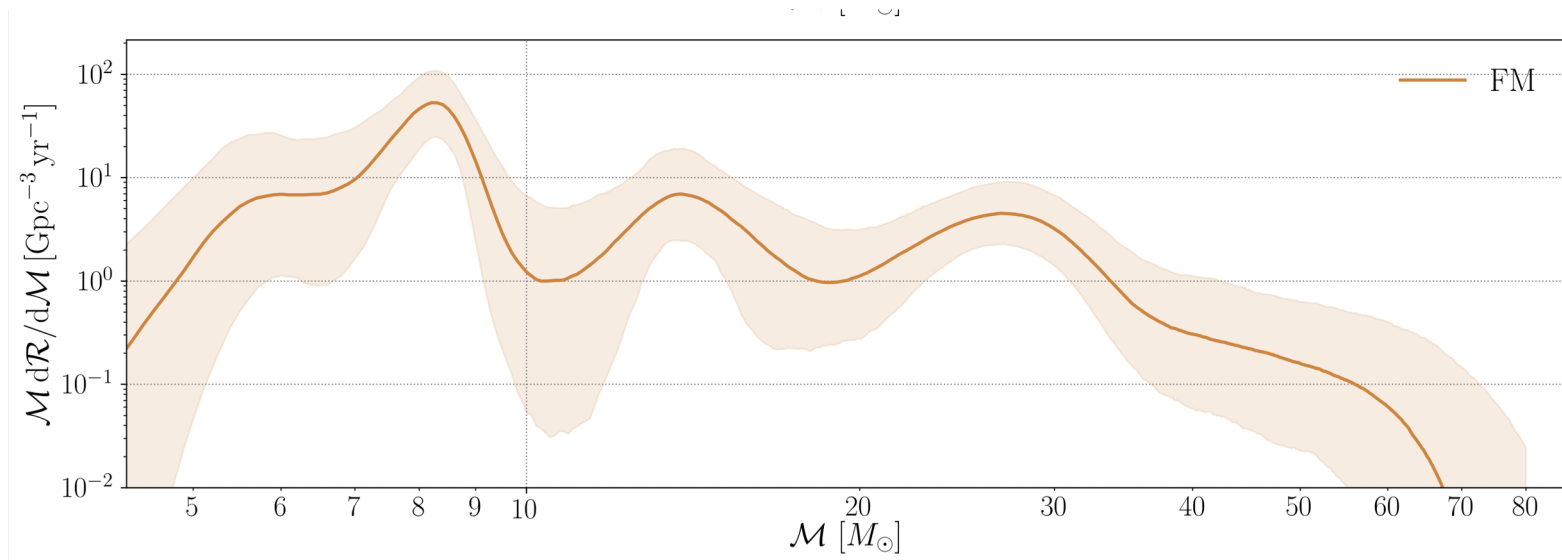
- Mass distributions
- Mass gaps
- Spin distribution
- Rates
- Background

Mass distribution

- Few events to reconstruct the NS mass distribution but no evidence for a peak around $1.35 M_{\text{solar}}$. Consistent with a uniform distribution.
- Dearth of observation between $3-5 M_{\text{solar}}$ but some events larger than the maximal mass supported by dense matter EOS about $2.2-2.5 M_{\text{solar}}$.
- No evidence for presence or absence of a mass gap

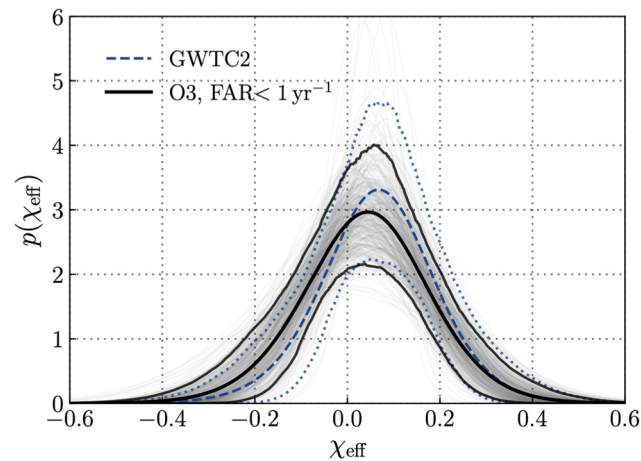
Mass distribution

- substructure in the BBH mass distribution
- no evidence for an upper pair-instability mass gap from $(40-70) M_{\text{solar}}$ to $120 M_{\text{solar}}$



Spin distribution

- small spin aligned with the orbital angular momentum for most systems.
- evidence for non zero spins
- evidence for non aligned spins could indicate dynamical formation



- evidence for mass ratio/magnitude spin correlation
- broadening of the spin distribution above $30 M_{\text{Solar}}$

Rate

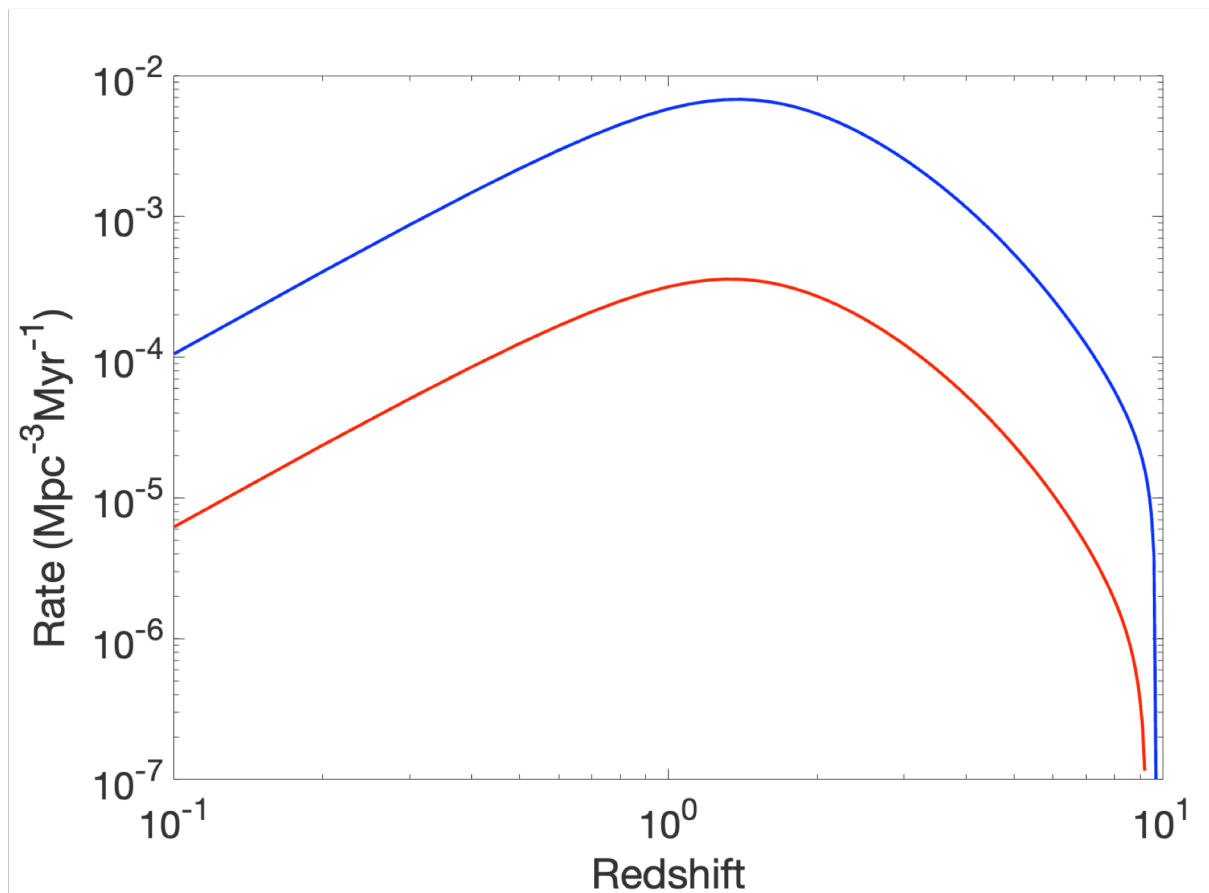
- Local rate estimates:

BNS: (13-1900) $\text{Gpc}^{-3} \text{yr}^{-1}$

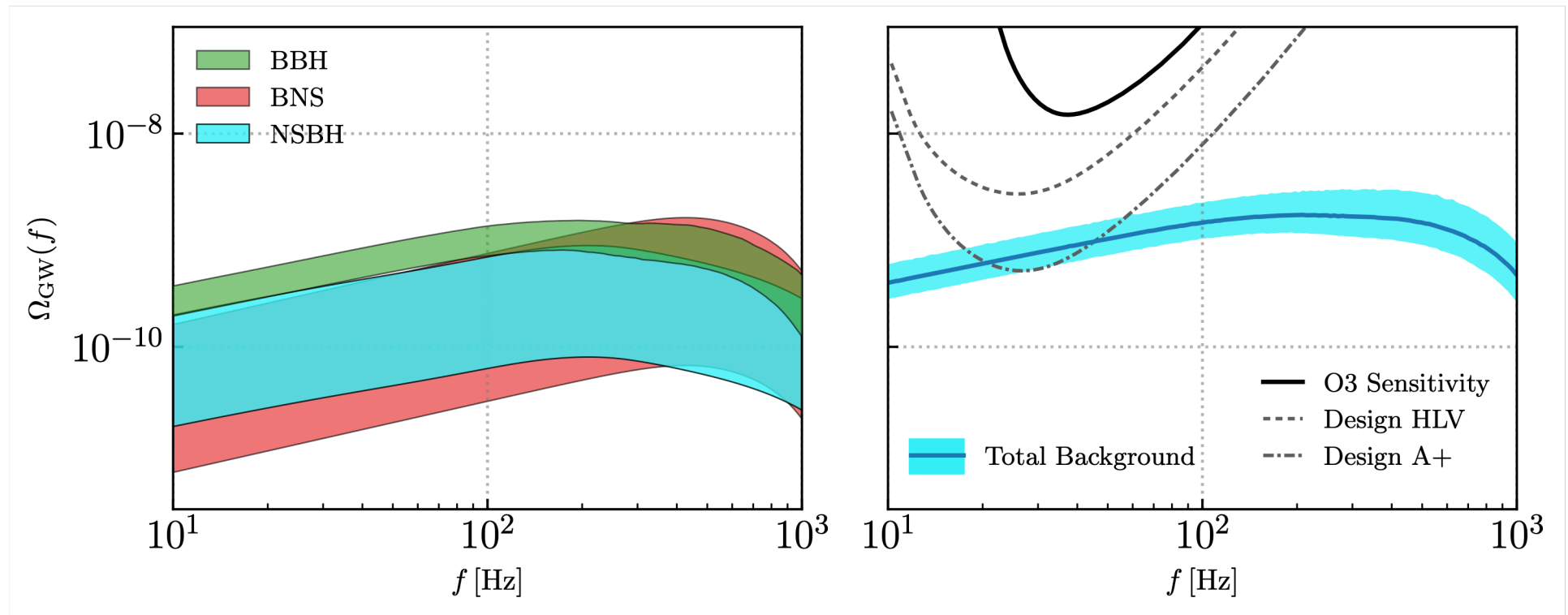
BHNS: (7.4-320) $\text{Gpc}^{-3} \text{yr}^{-1}$

BBH: (16-130) $\text{Gpc}^{-3} \text{yr}^{-1}$

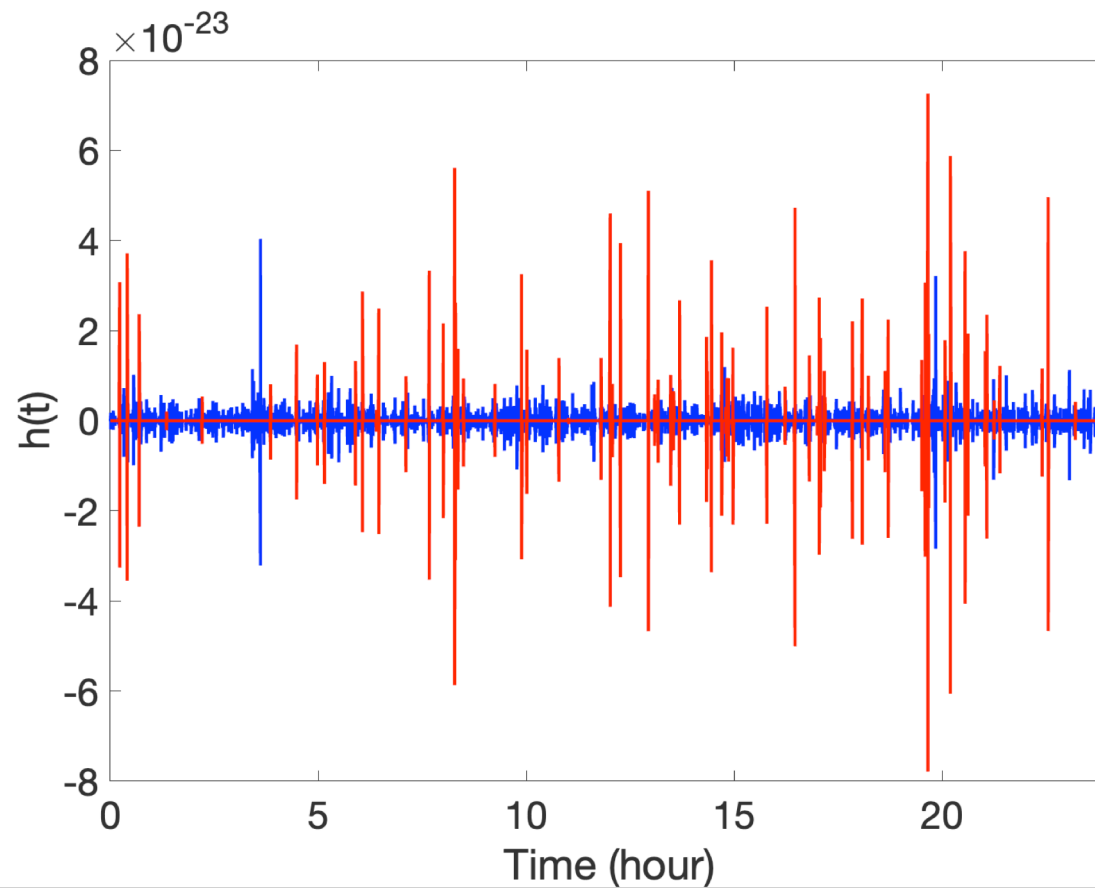
- Increase of the rate with redshift consistent with $(1+z)^3$ but small volume



Background



Properties in the time domain



Conclusions

- GWTC3 includes 90 events with $p_{\text{astro}} > 0.5$
- BHNS observed for the first time
- no evidence for NS-BH mass gap or PI mass gap
- structure in the mass distribution for BHs
- non zero and non aligned spins that can probe dynamical formation
- background from unresolved CBCs may be detected with A+

NO I SURE PING PONG @ LIGO

LIGO CHECKLIST

- BINARY SYSTEM
- BLACK HOLES
- NEUTRON STARS
 - WITH EM COUNTERPART
- BH-NS
- SUPERNOVAE
- PULSARS
- STOCHASTIC

AZ/21

... ..