The Observation of Gravitational Waves from Binary Black Hole Mergers by LIGO

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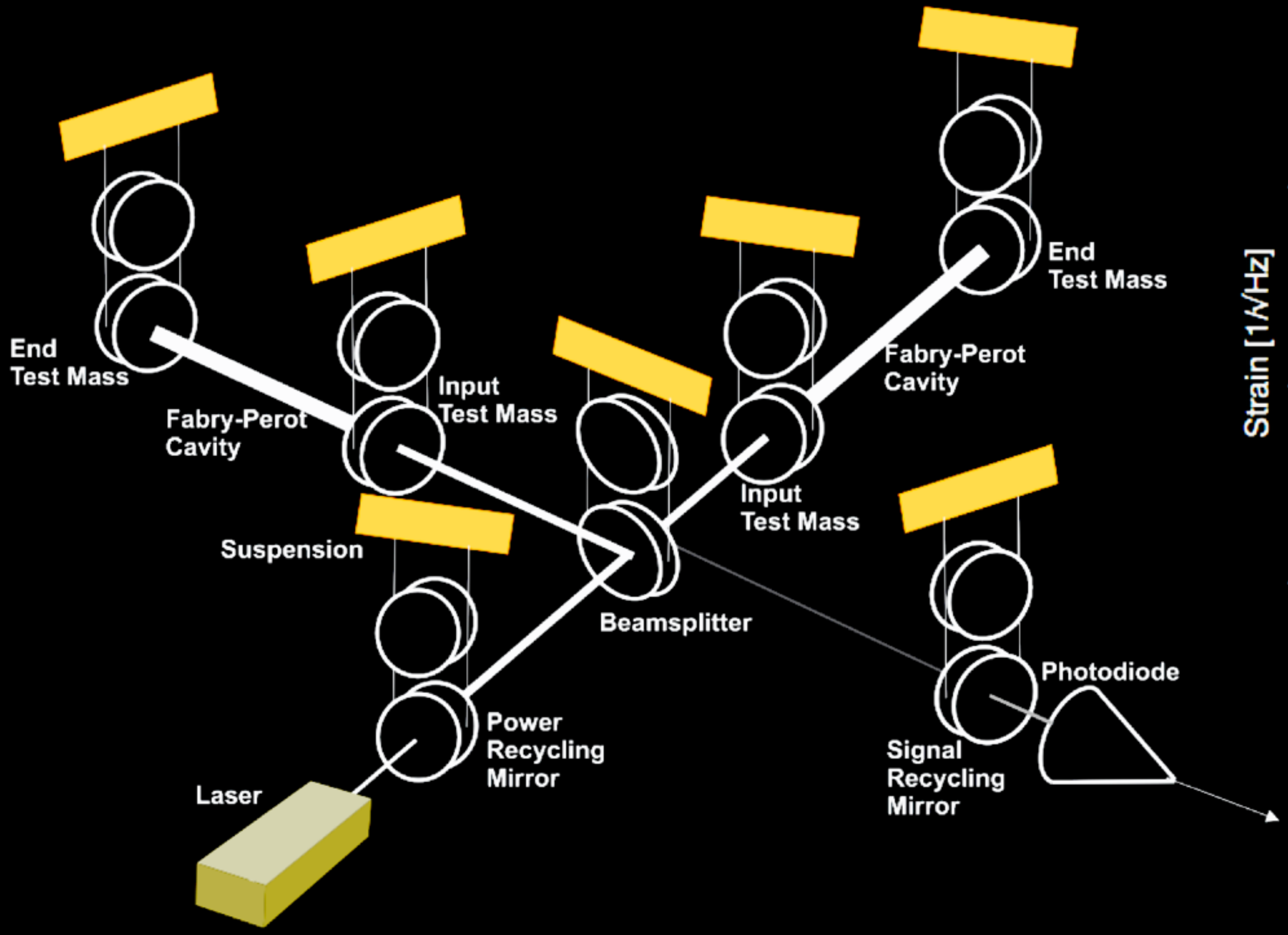
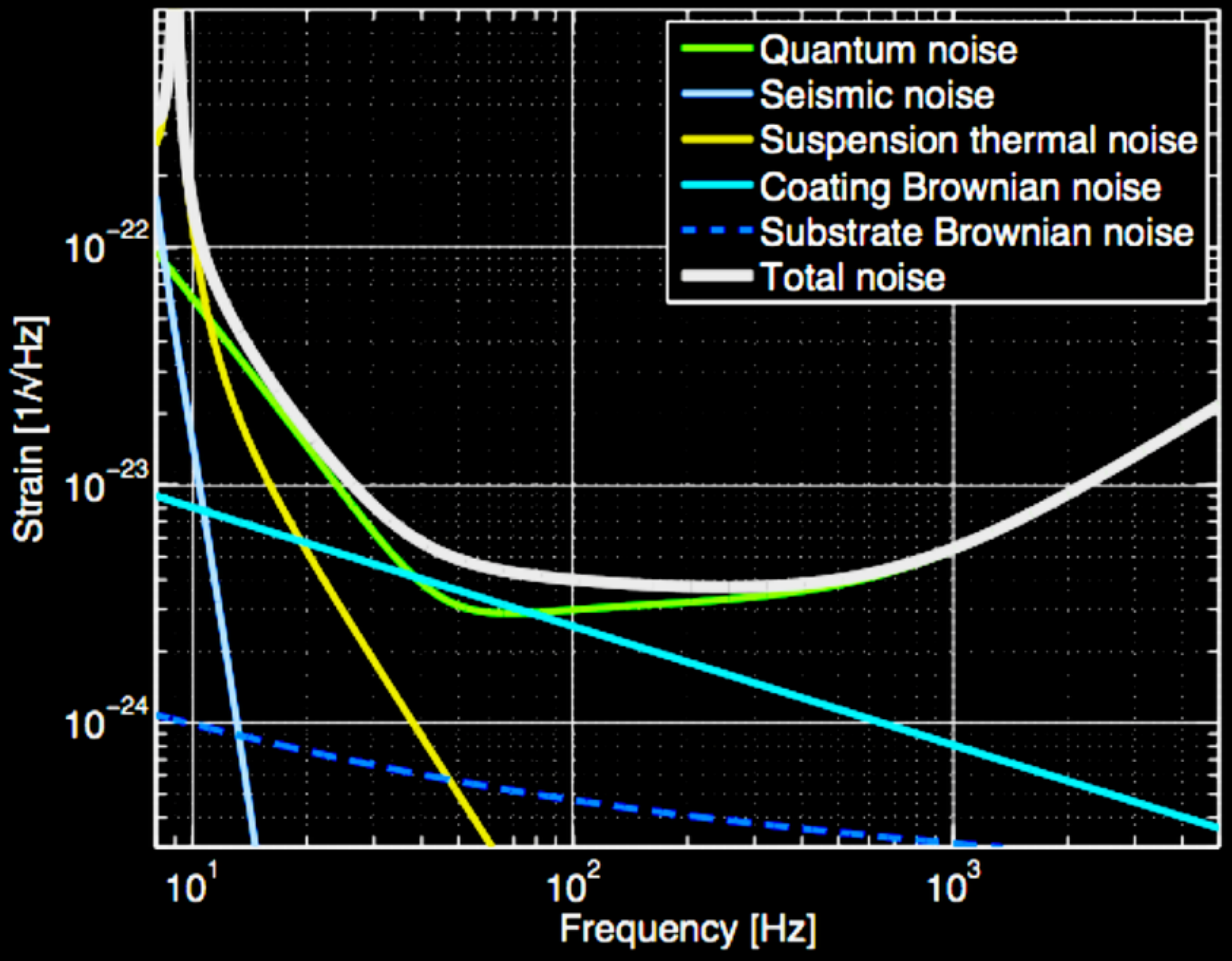
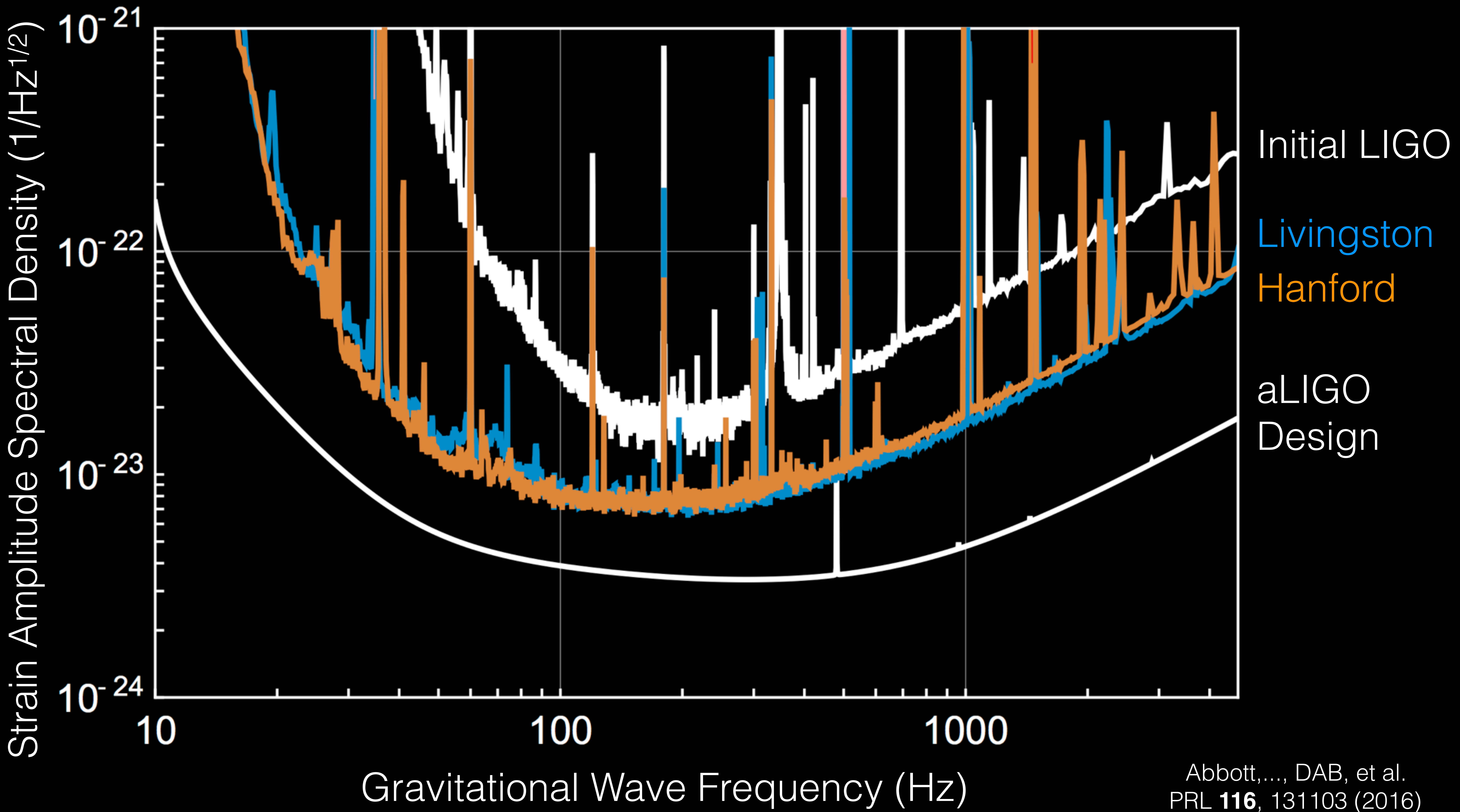
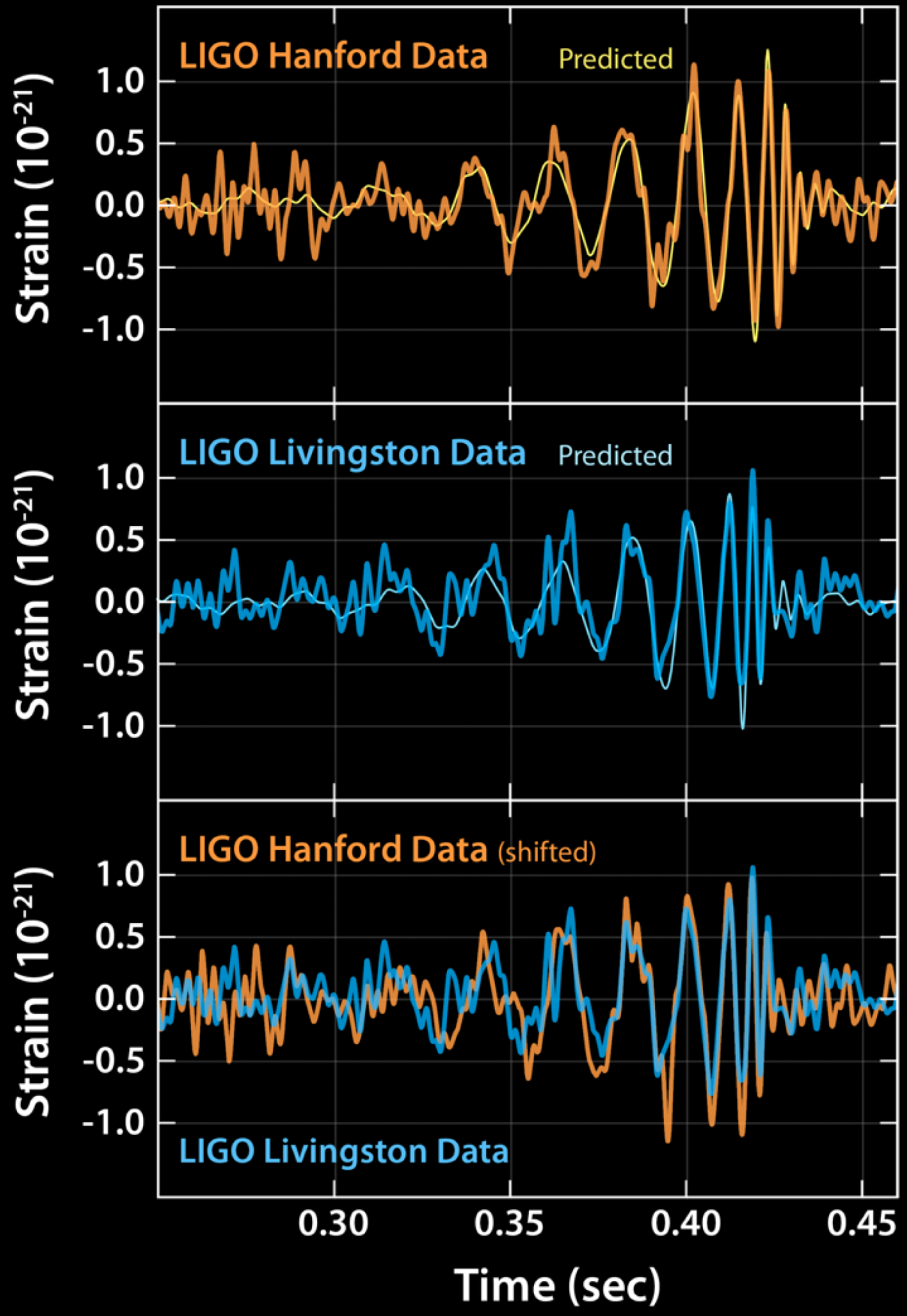
Advanced LIGO







Abbott,..., DAB, et al.
PRL **116**, 131103 (2016)



GW150914

- Observed September 14, 2015 09:50:45 UTC
- The signal is seen first by the Livingston detector and then 7ms later at Hanford
- Over 0.2 seconds, the signal increases in frequency and amplitude in about 8 cycles from 35 Hz to a peak amplitude at 150 Hz

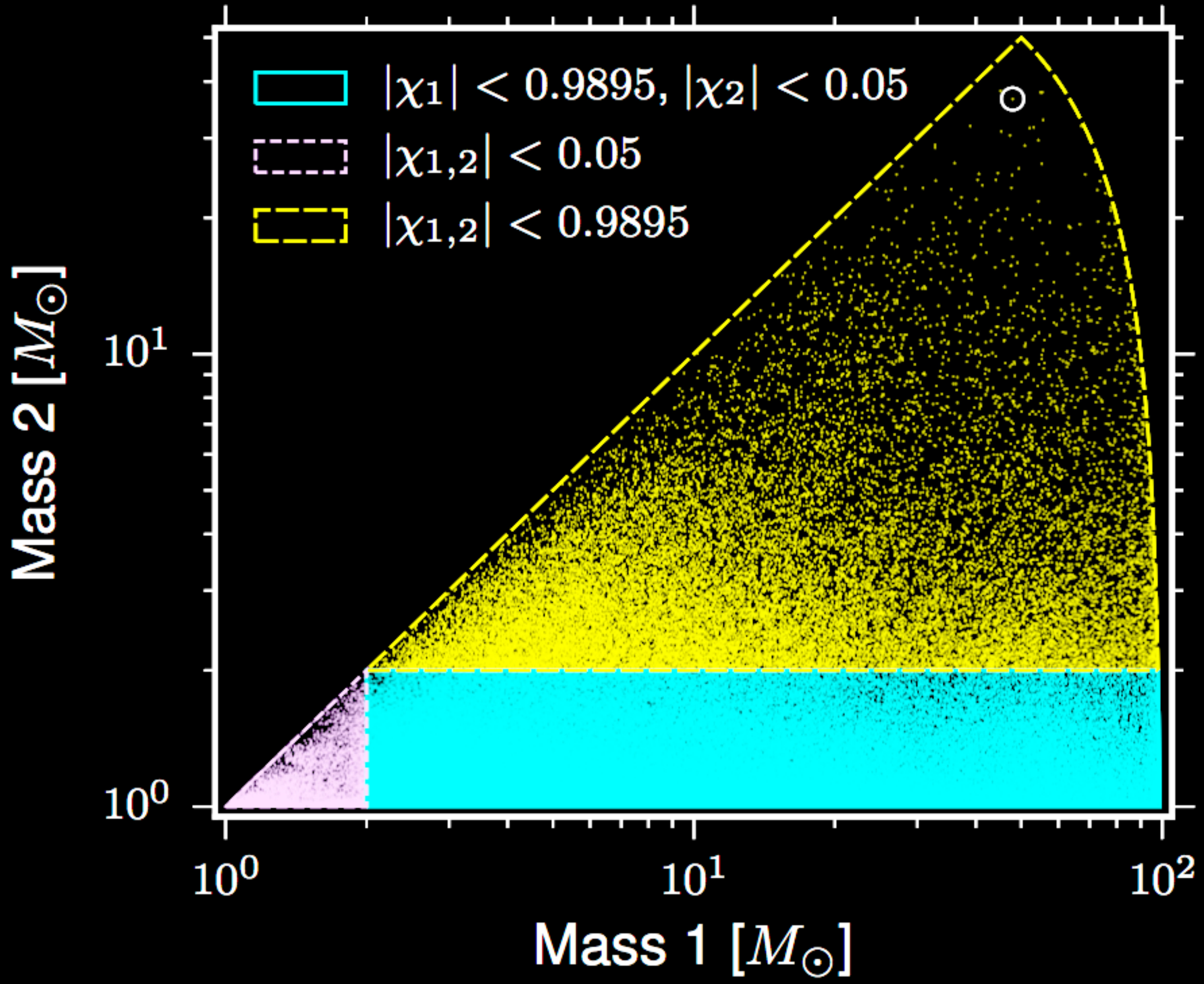
Abbott, ..., DAB, et al. PRL **116** 061102 (2016)

To detect signals from compact-object binaries, we construct a bank template waveforms and matched-filter the data

$$\rho = \frac{\langle s|h\rangle}{\sqrt{\langle h|h\rangle}}$$

$$\langle a|b\rangle = 4\mathrm{Re}\int_{f_{\mathrm{low}}}^{f_{\mathrm{high}}} \frac{\tilde{a}(f)\tilde{b}(f)}{S_n(f)}\, df$$

Apply additional waveform-consistency tests to separate signal from noise

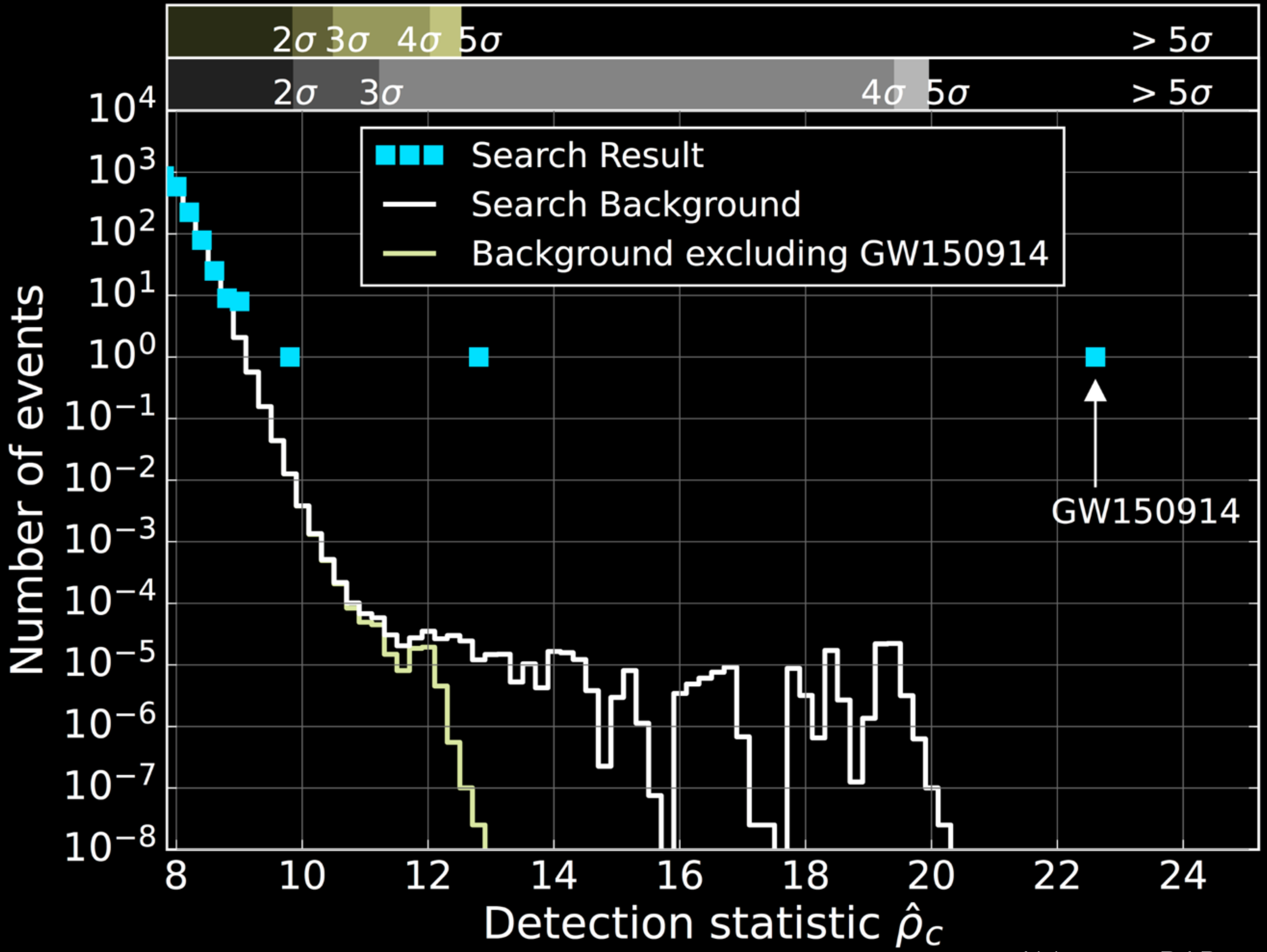


Allen,... , DAB, et al. Phys Rev D 85 122006 (2012)
Babak,..., DAB, et al. Phys Rev D 87 024033 (2013)
Usman,... DAB, et al. arXiv:1508.02357
Capano, et al. arXiv:1602.03509
Abbott, ..., DAB, et al. arXiv:1602.03839
DAB, et al., Phys. Rev. D 86 084017 (2012)

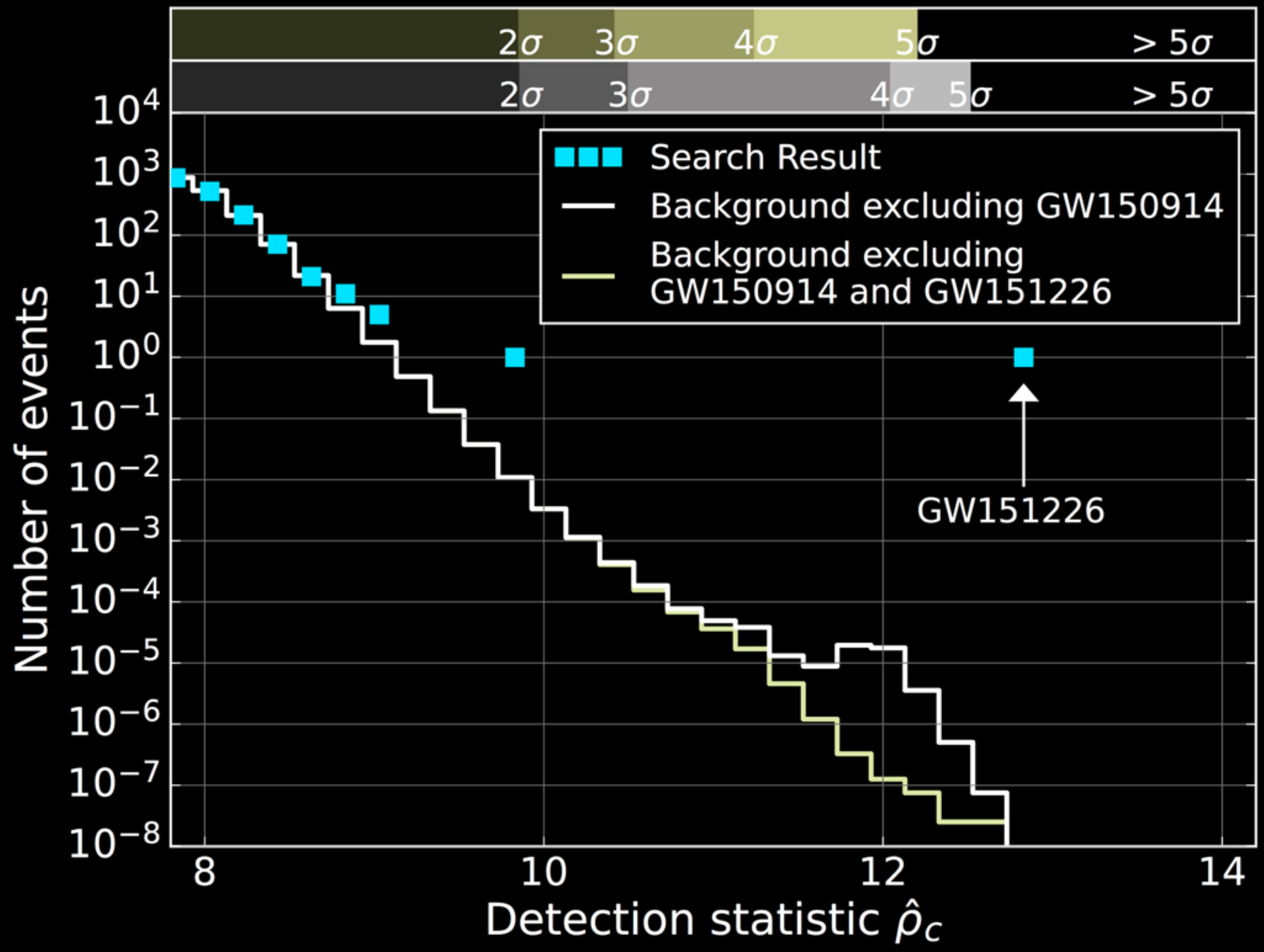
September 12, 2015 to January 19, 2016

Abbott, ..., DAB, et al. arXix:1606.04856

Abbott, ..., DAB, et al. arXix:1607.07456

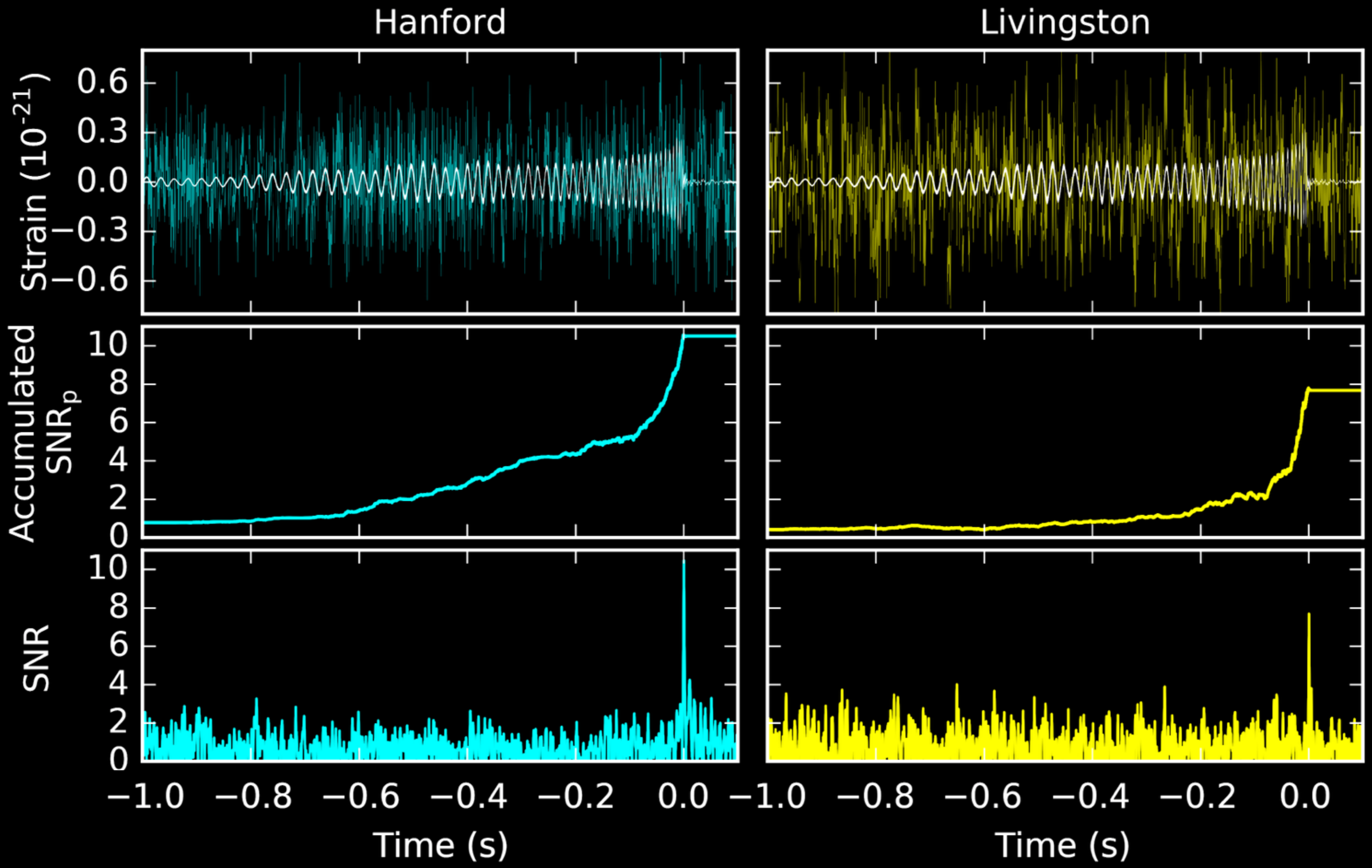


Abbott, ..., DAB, et al. arXix:1606.04856



- Detection significance greater than 5 sigma
- Merger of a 14.2 solar mass black hole and a 7.5 solar mass black hole
- Luminosity distance 440 Mpc

Abbott, ..., DAB, et al. Phys. Rev. Lett. **116**, 241103 (2016)



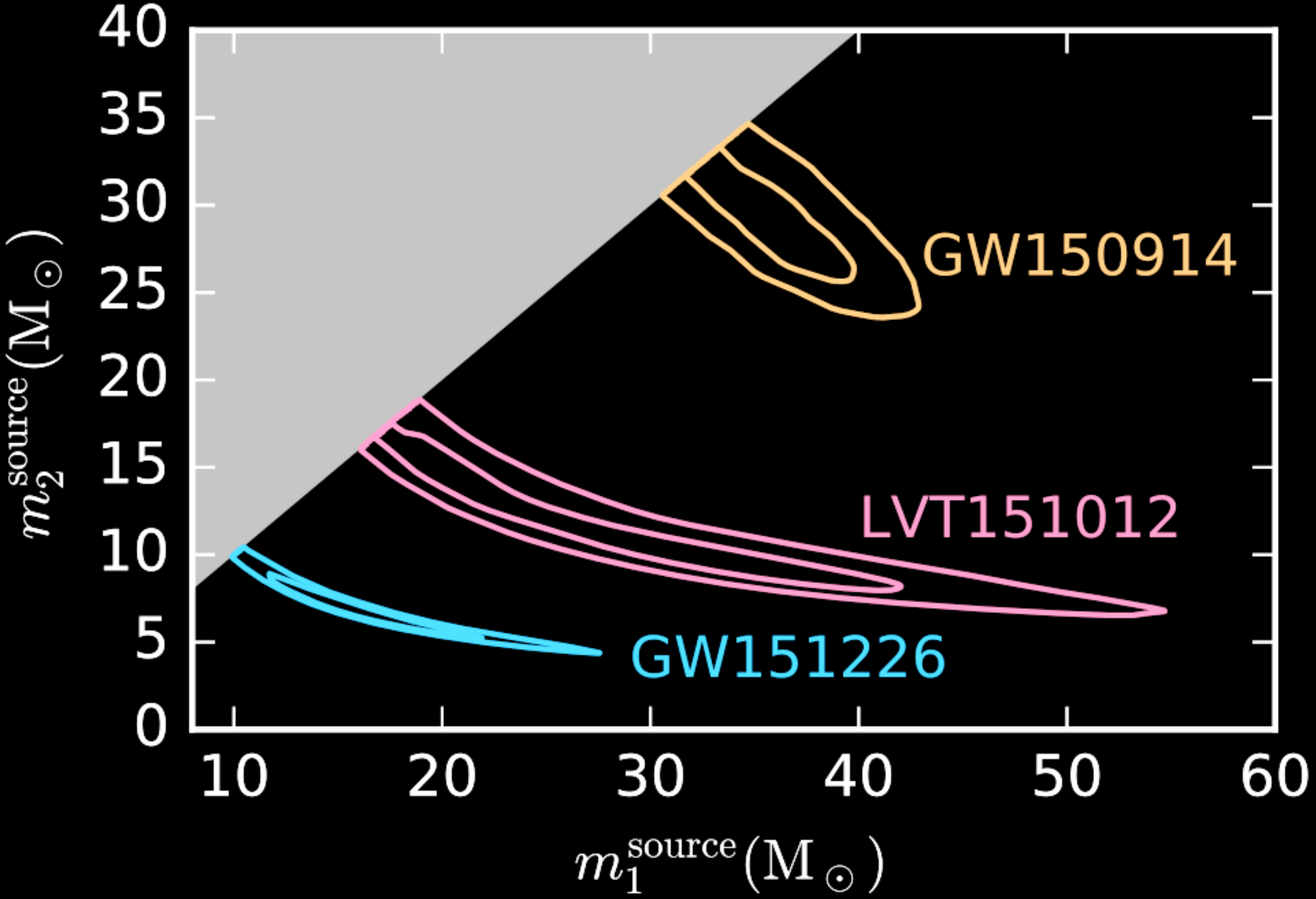
Abbott, ..., DAB, et al. Phys. Rev. Lett. **116**, 241103 (2016)

Abbott, ..., DAB, et al. arXix:1606.04856

	GW150914	GW151226	LVT151012
Source Mass 1	$36.2^{+5.2}_{-3.8}\ M_\odot$	$14.2^{+8.3}_{-3.7}\ M_\odot$	$23^{+18}_{-6}\ M_\odot$
Source Mass 2	$29.1^{+3.7}_{-4.4}\ M_\odot$	$7.5^{+2.3}_{-2.3}\ M_\odot$	$13^{+4}_{-5}\ M_\odot$
Luminosity Distance	420^{+150}_{-180} Mpc	440^{+180}_{-190} Mpc	1000^{+500}_{-500} Mpc

Abbott, ..., DAB, et al. arXix:1606.04856

- Lowest mass is the GW151226 secondary $m_2 \geq 5.6 M_\odot$ (90% confidence)
- Highest mass is GW150914 remnant $m \geq 59.2 M_\odot$ (90% confidence)
- Mass ratios differ:
  - GW150914 near equal mass
  - GW151226 and LVT151012 have support for unequal mass ratios



Abbott, ..., DAB, et al. arXix:1606.04856

- Only weak constraints can be placed on spin magnitudes
- In all cases, the uncertain spans the full range of spins [0,1]
- Can best measure the spin of the larger black hole
- Smaller spins are favored for all systems. At 90% confidence

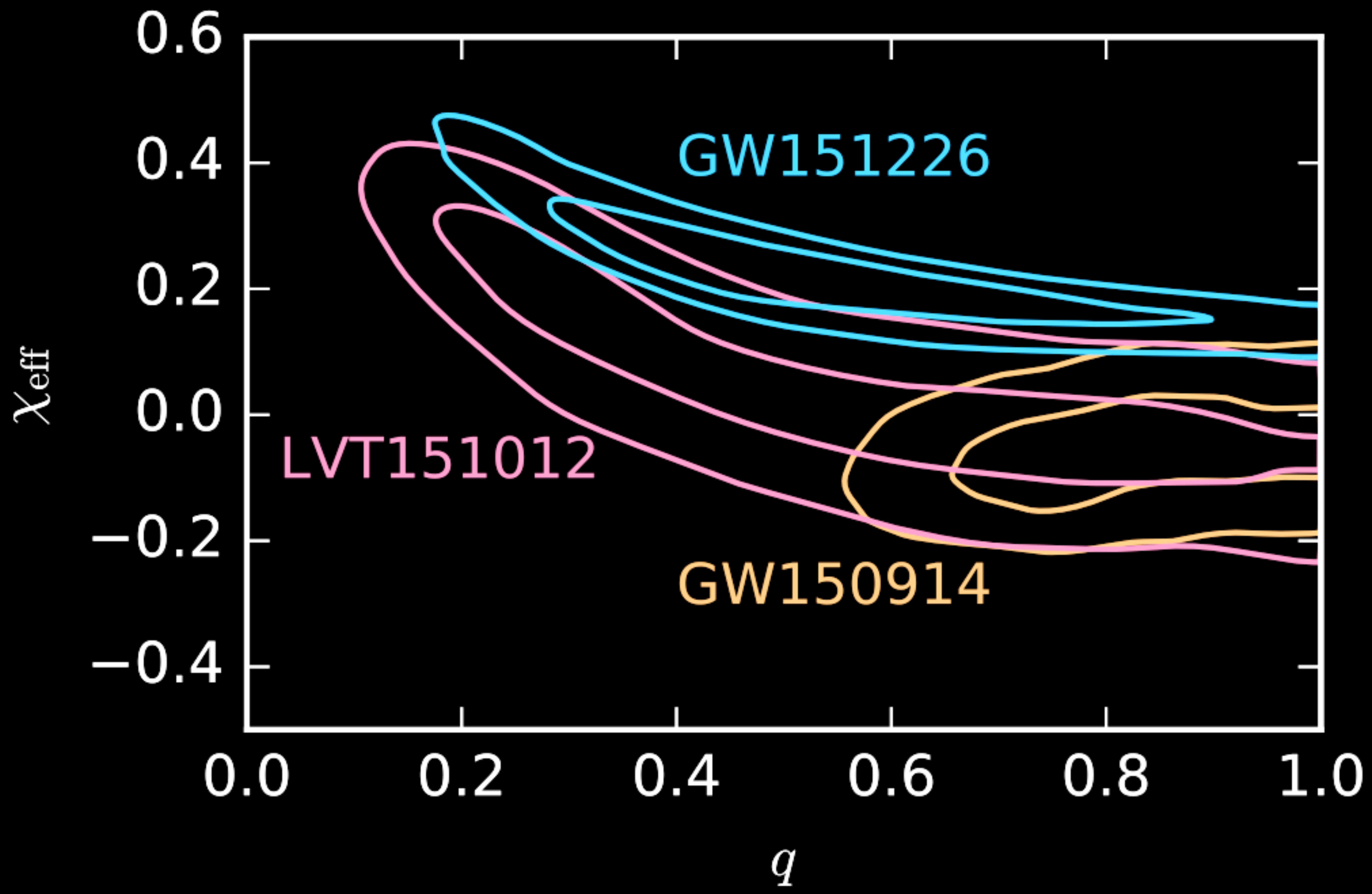
$$a_1^{\mathrm{GW150914}} \leq 0.7 \quad a_1^{\mathrm{GW151226}} \leq 0.7 \quad a_1^{\mathrm{LVT151012}} \leq 0.8$$

- For GW151226, at least one component has $a \geq 0.2$ $(99\% \text{ confidence})$
- We can better constrain $\chi_{\text{eff}} = \dfrac{\chi_1 m_1 + \chi_2 m_2}{M}$

  where $\chi_{1,2} = \dfrac{c}{Gm_{1,2}^2}\ \vec{S}_{1,2} \cdot \hat{L}$
- At 90% confidence for GW150914, GW151226, LVT151012

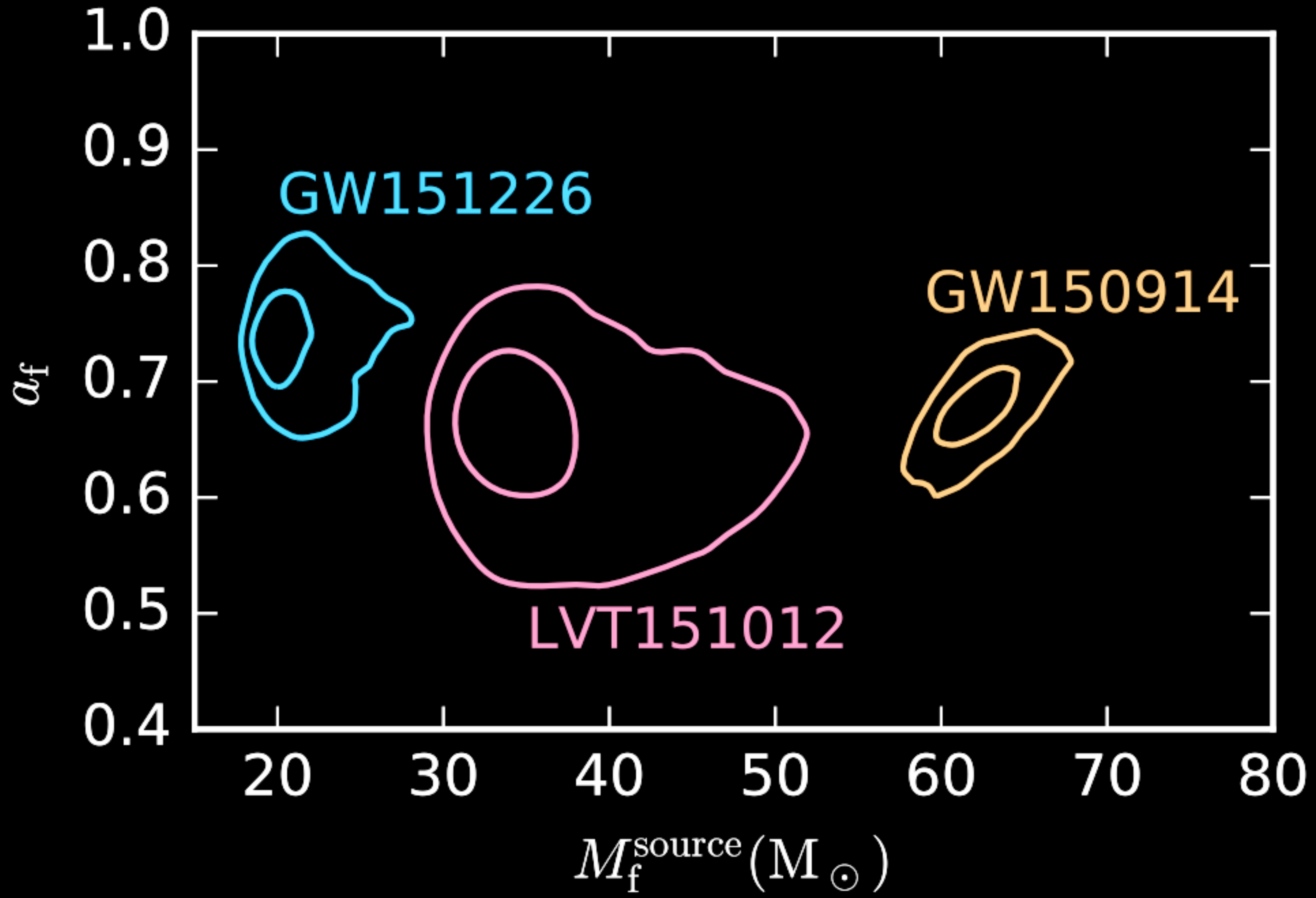
$$|\chi_{\text{eff}}| \leq 0.17, 0.28, 0.35$$

- Larne spins parallel to angular momentum are disfavored

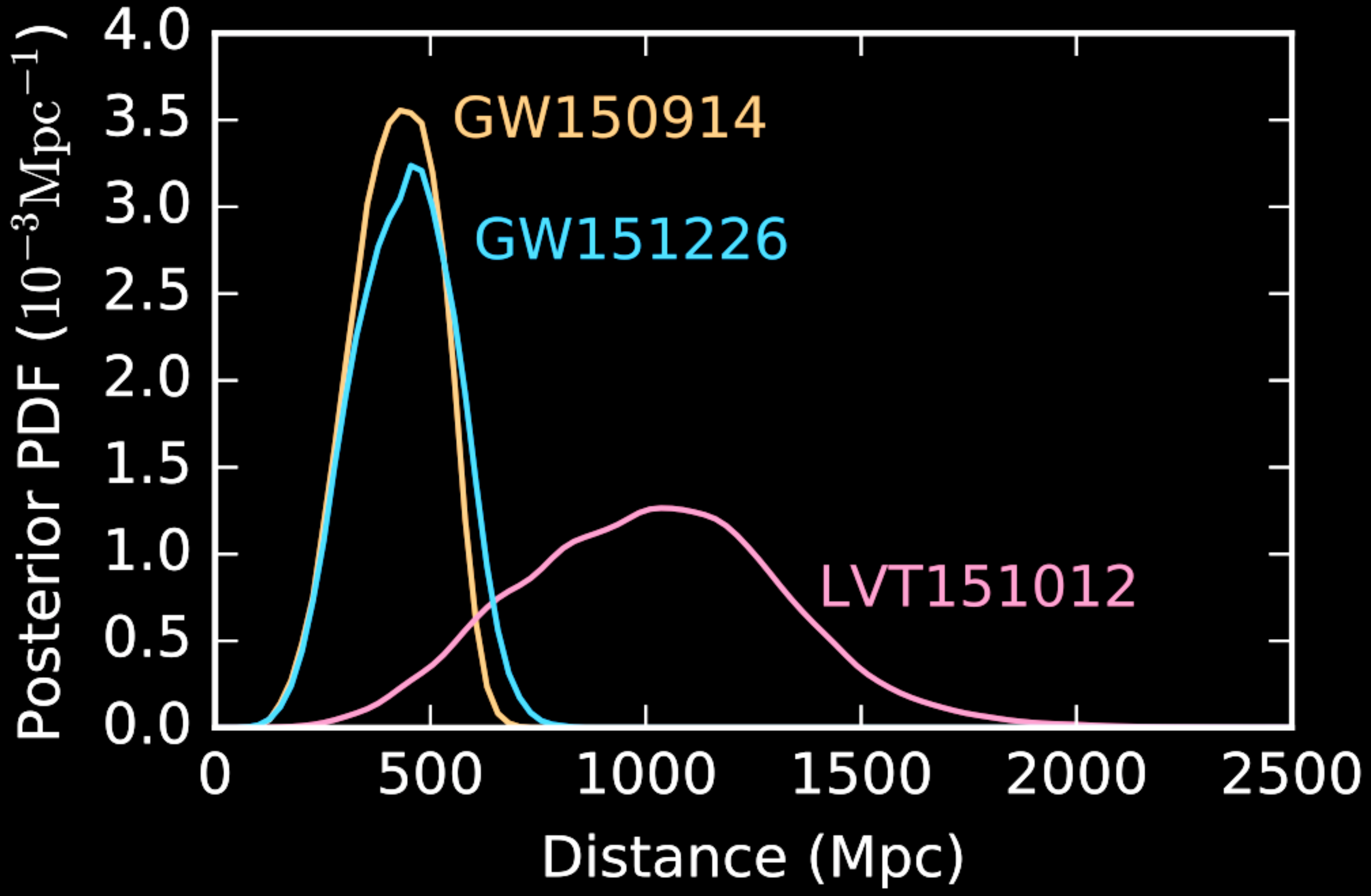


Abbott, ..., DAB, et al. arXix:1606.04856

- All three remnant black holes have spins ~ 0.7 as expected for the merger of similar mass black holes in a binary



Abbott, ..., DAB, et al. arXix:1606.04856



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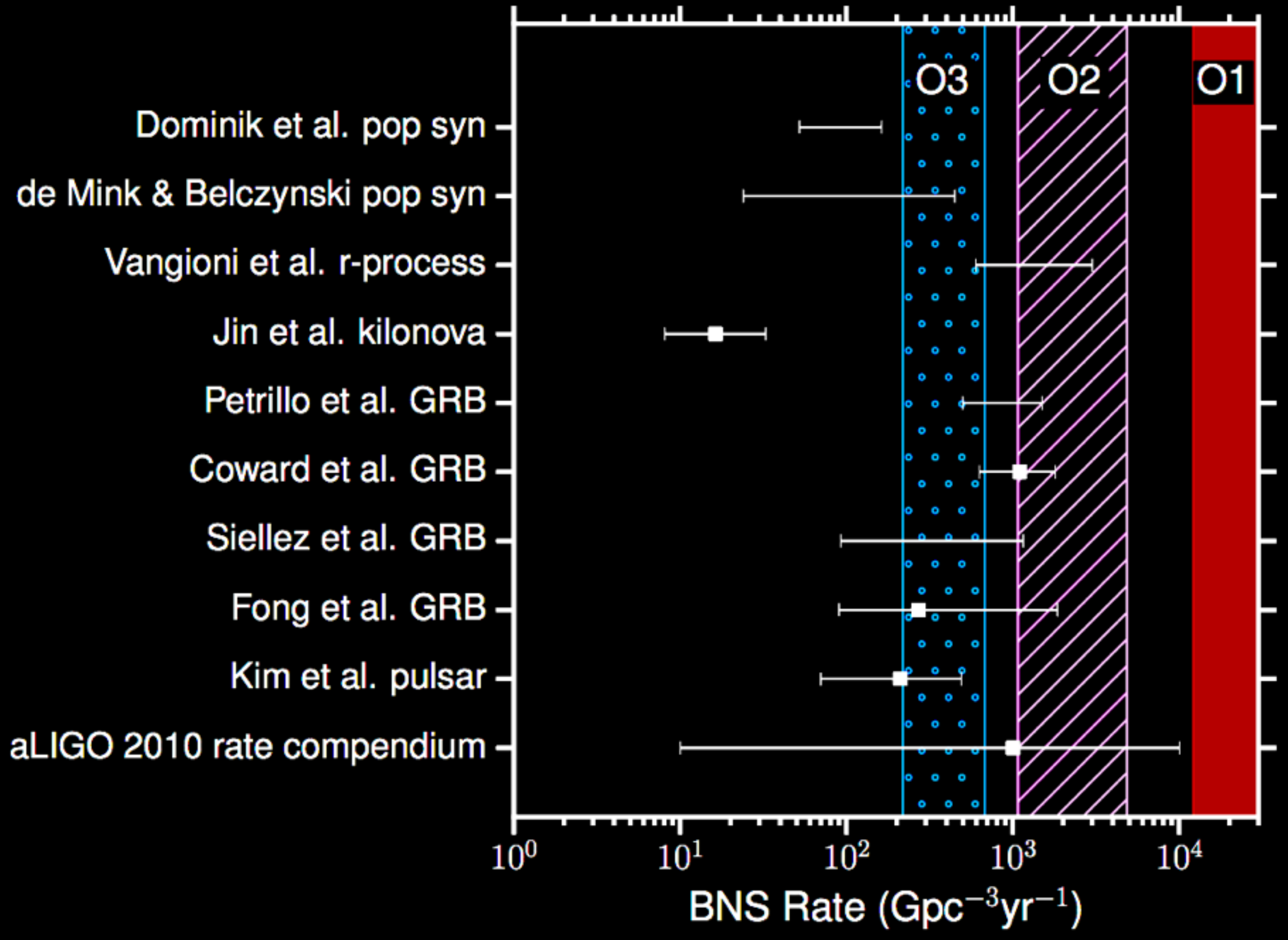
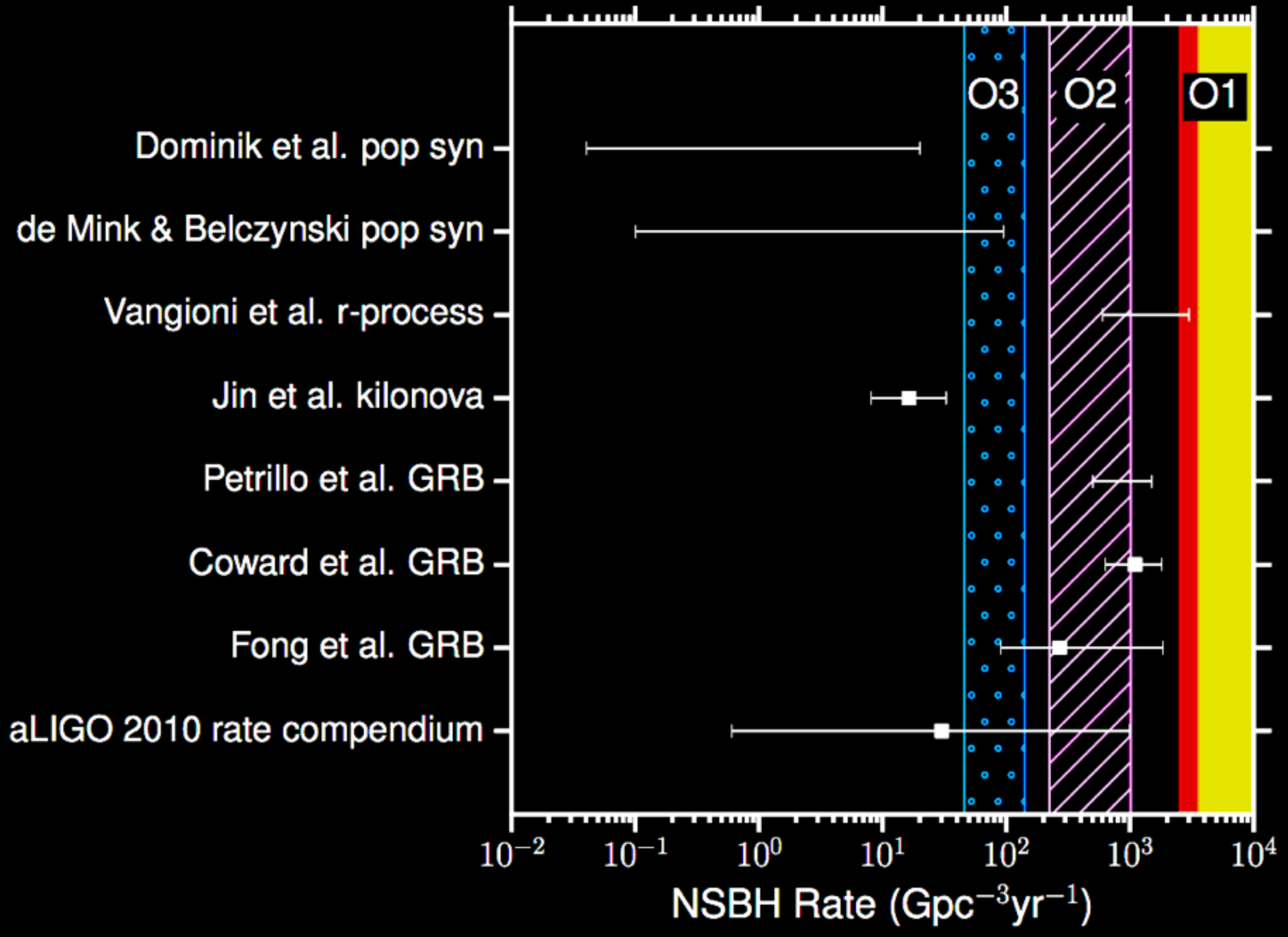
No significant BNS or NSBH candidates in O1





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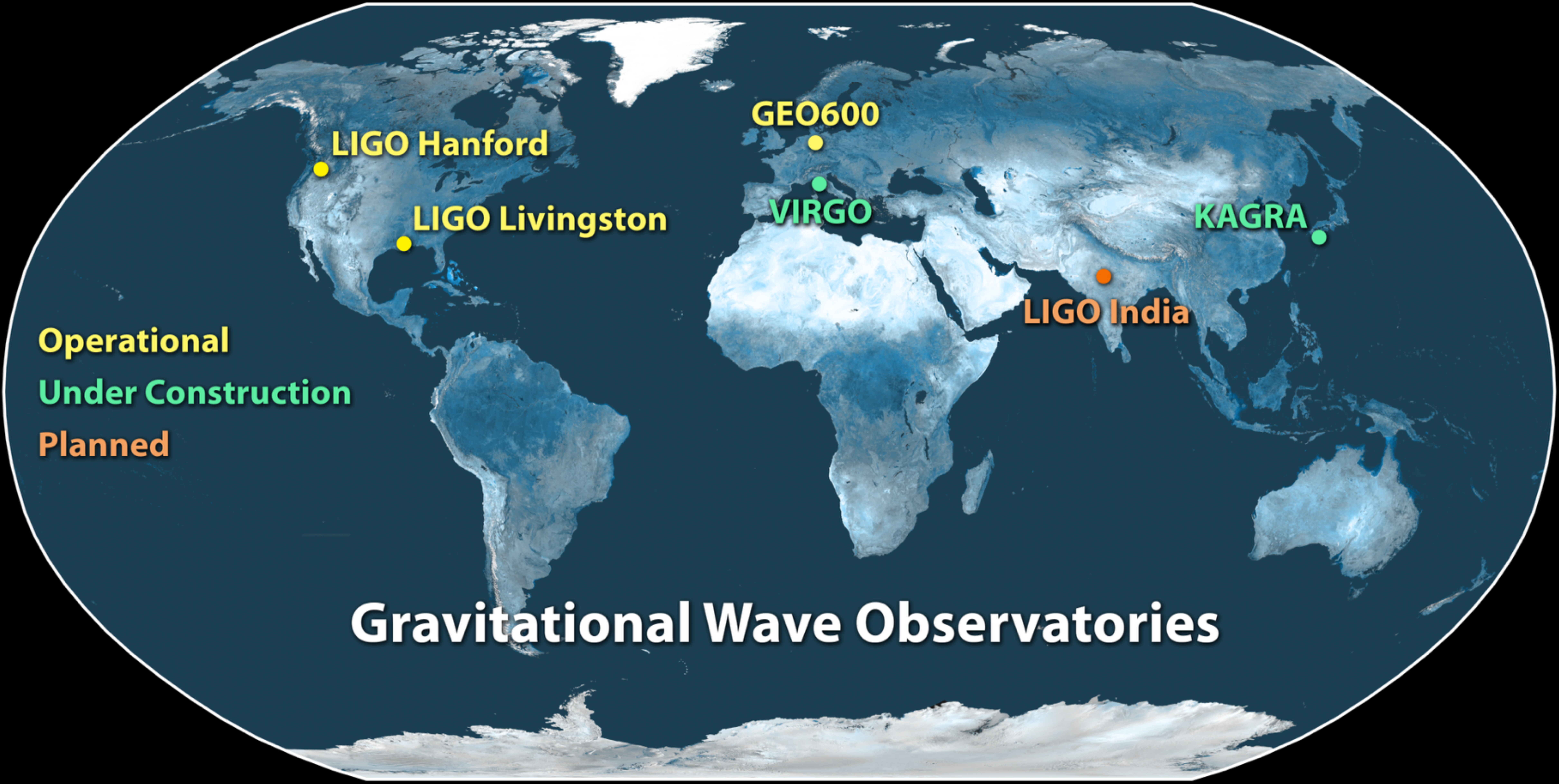
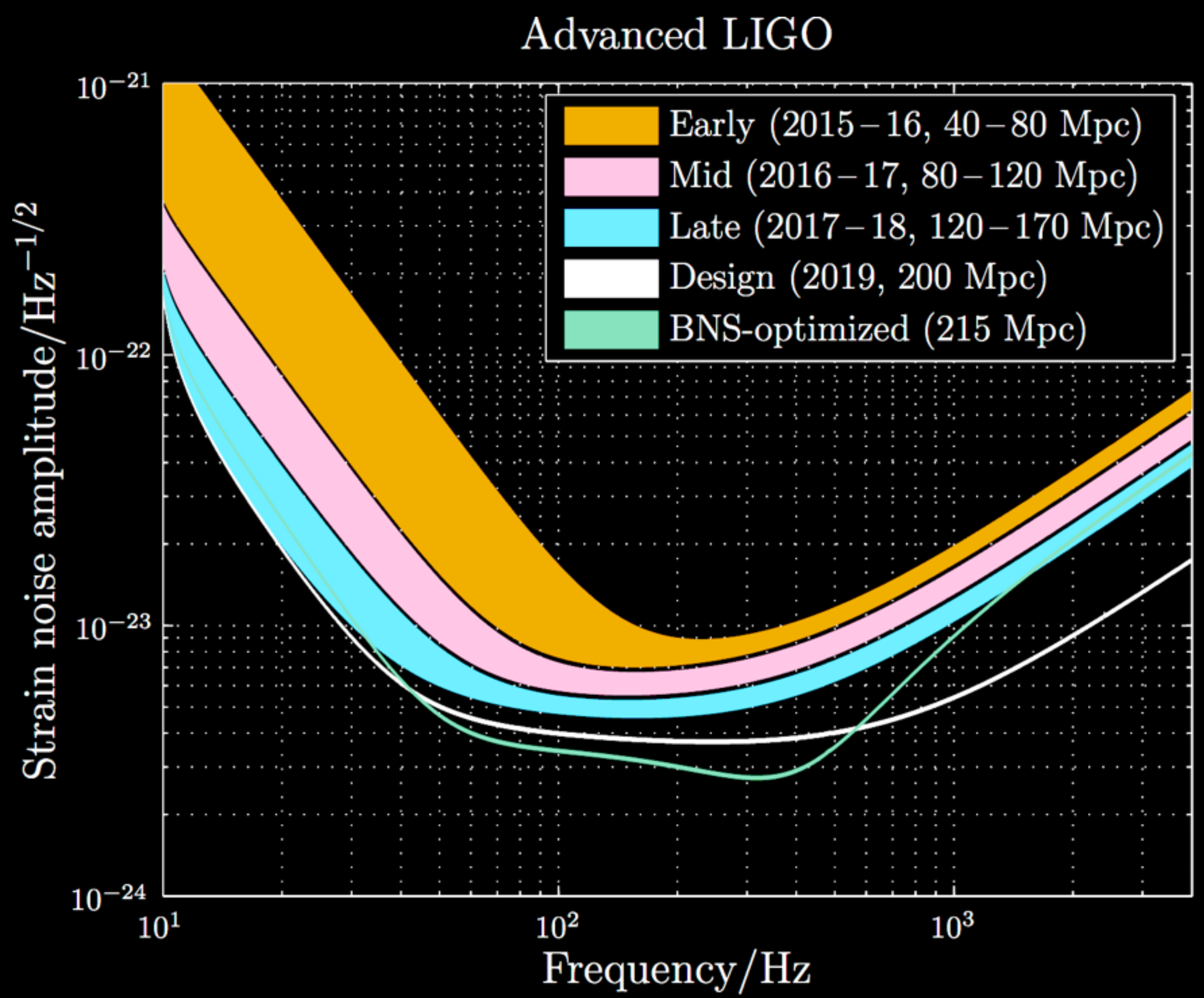
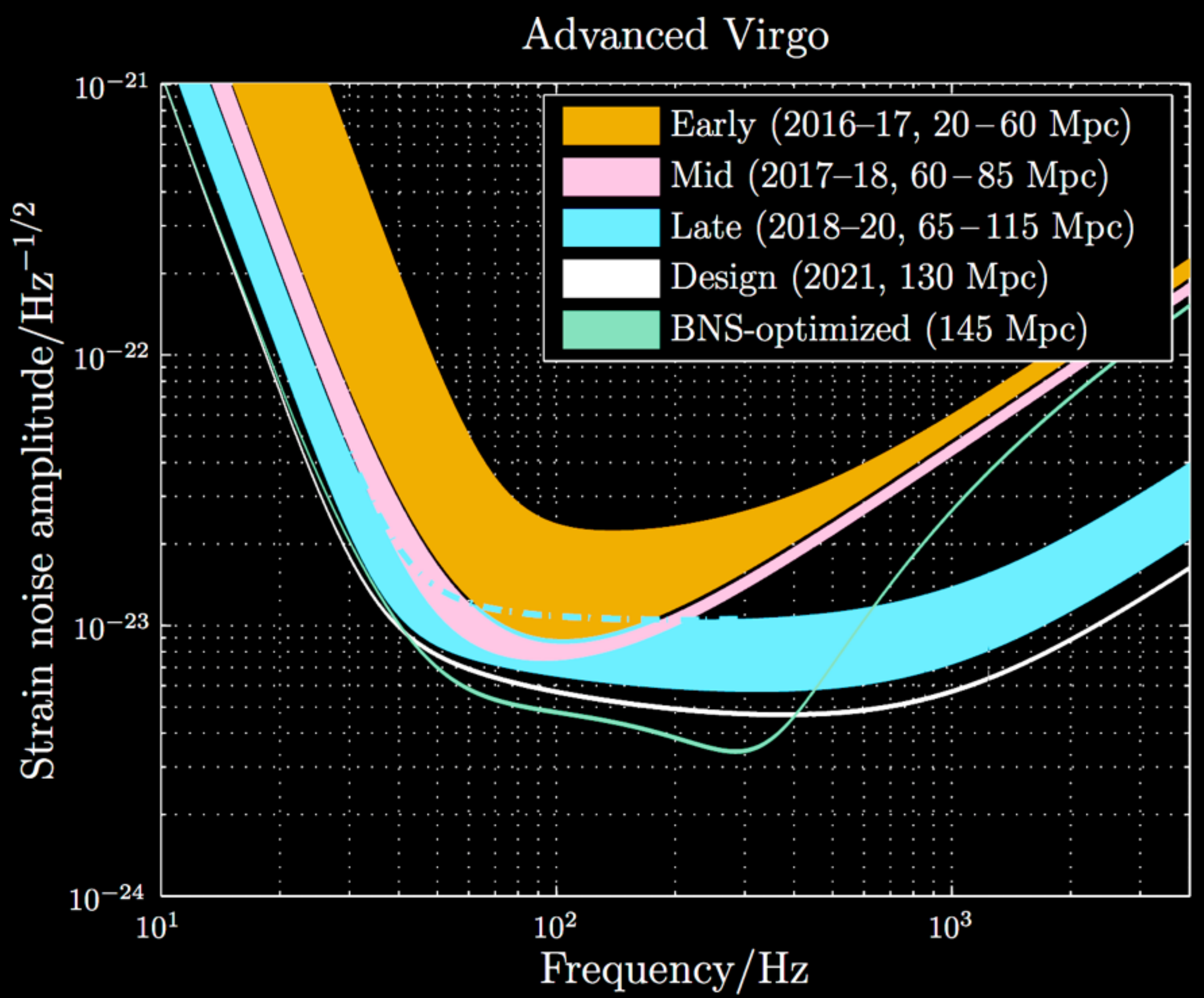


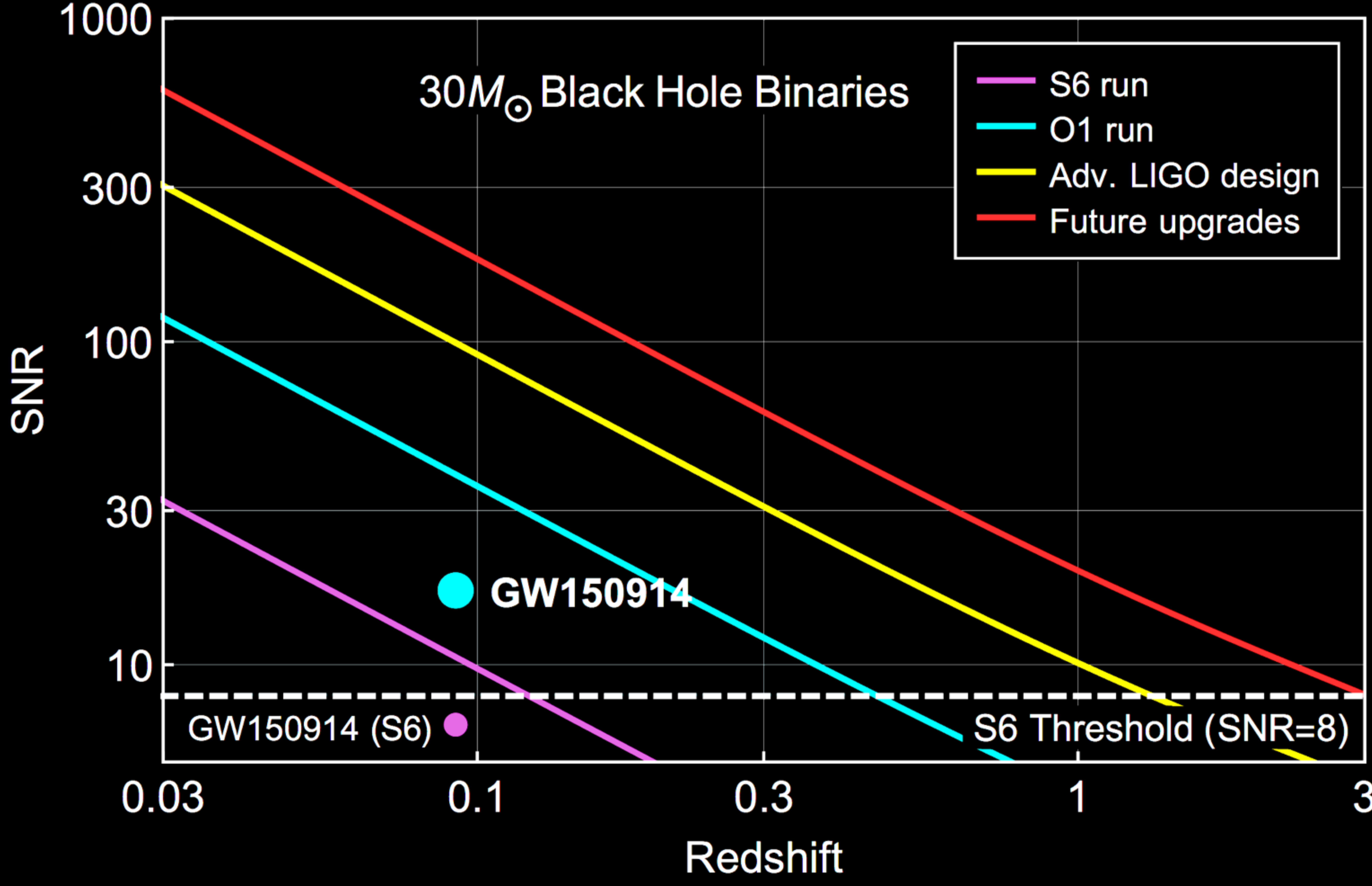
GEO600
LIGO Hanford
LIGO Livingston
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

- Advanced LIGO's sensitivity was at the upper end of that predicted for the first observing run

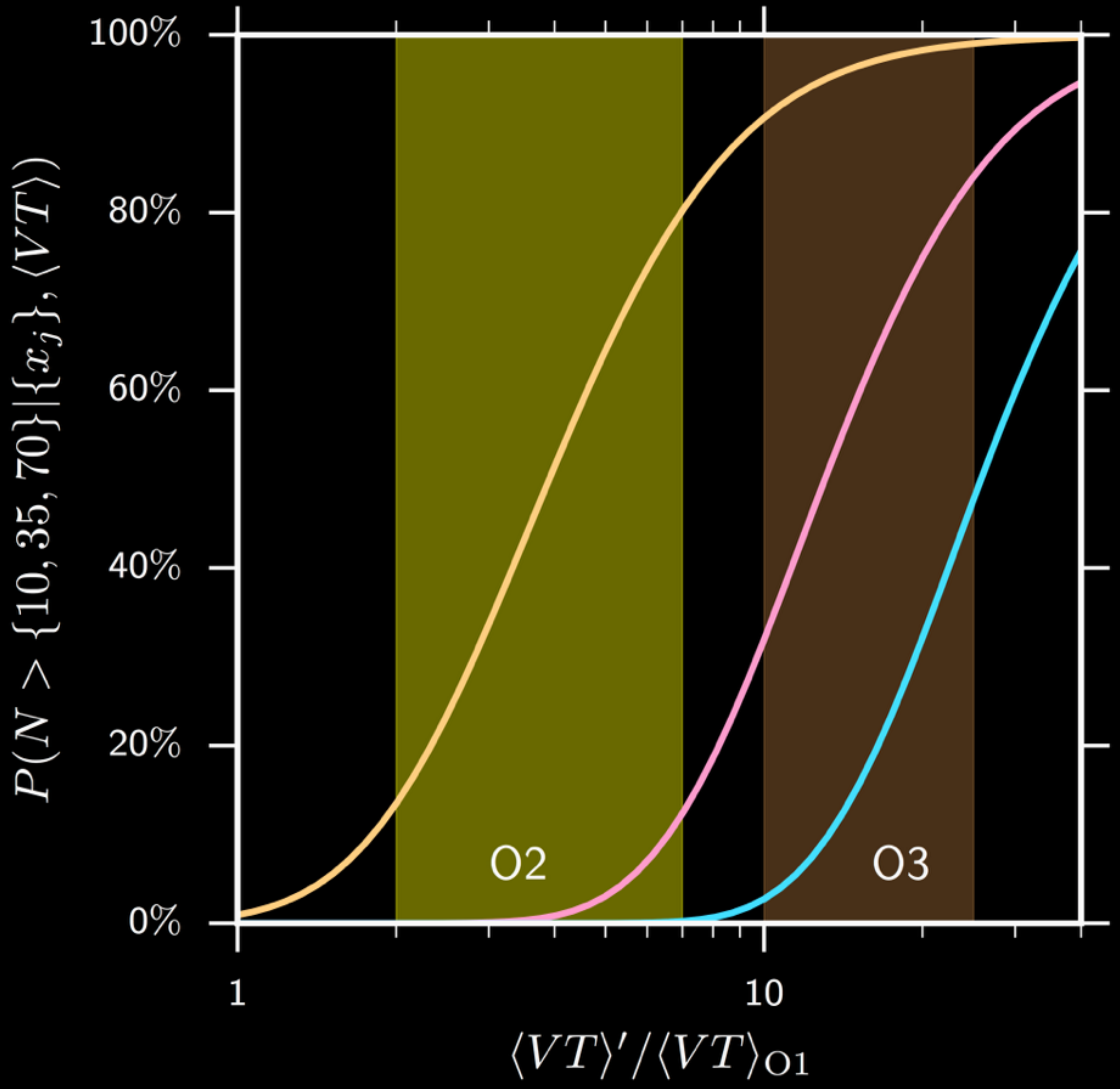




Abbott, ..., DAB, et al. Living Reviews in Relativity **19**, 1 (2016)



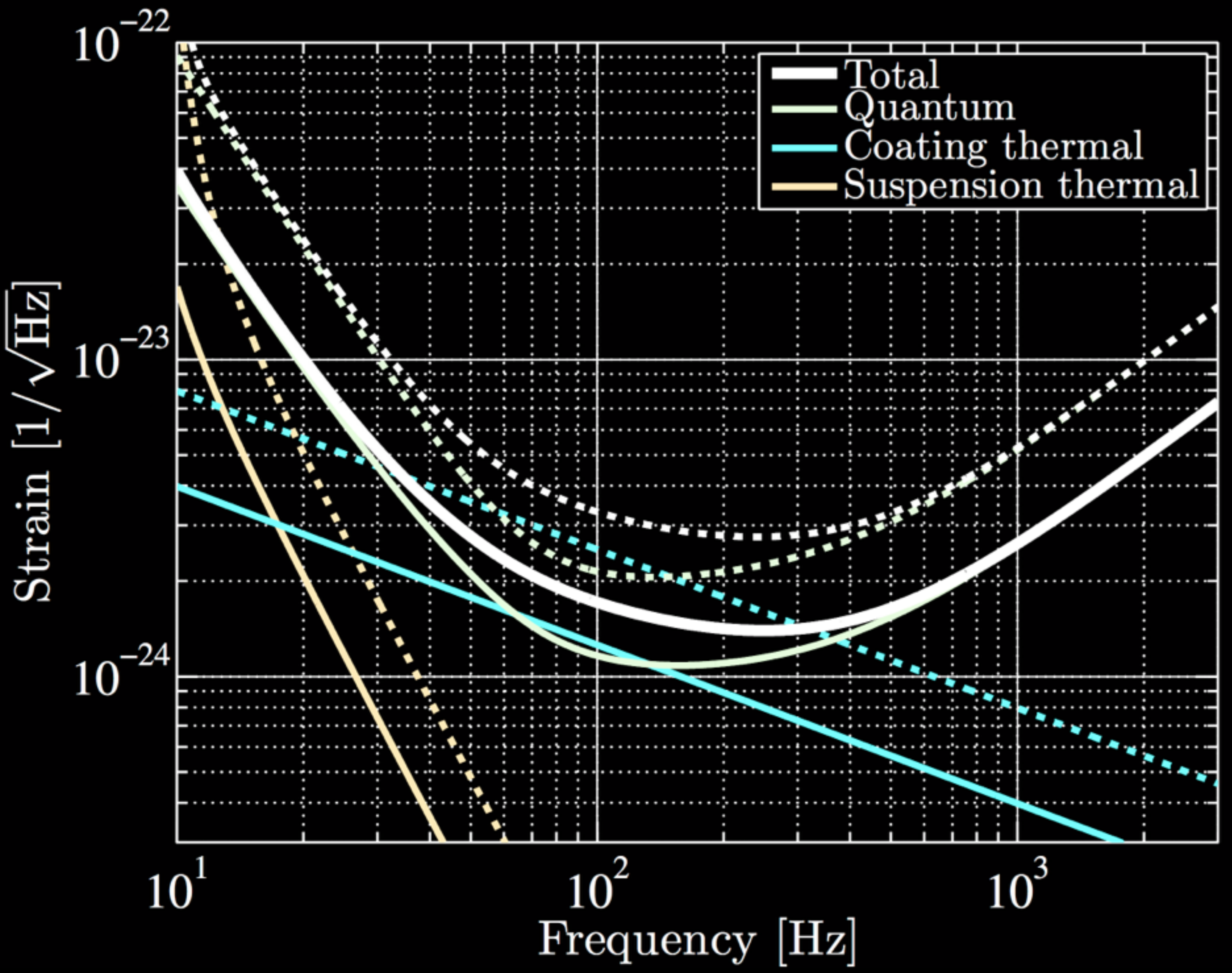
Abbott,... DAB, et al. Phys. Rev. Lett. **116**, 131103 (2016)



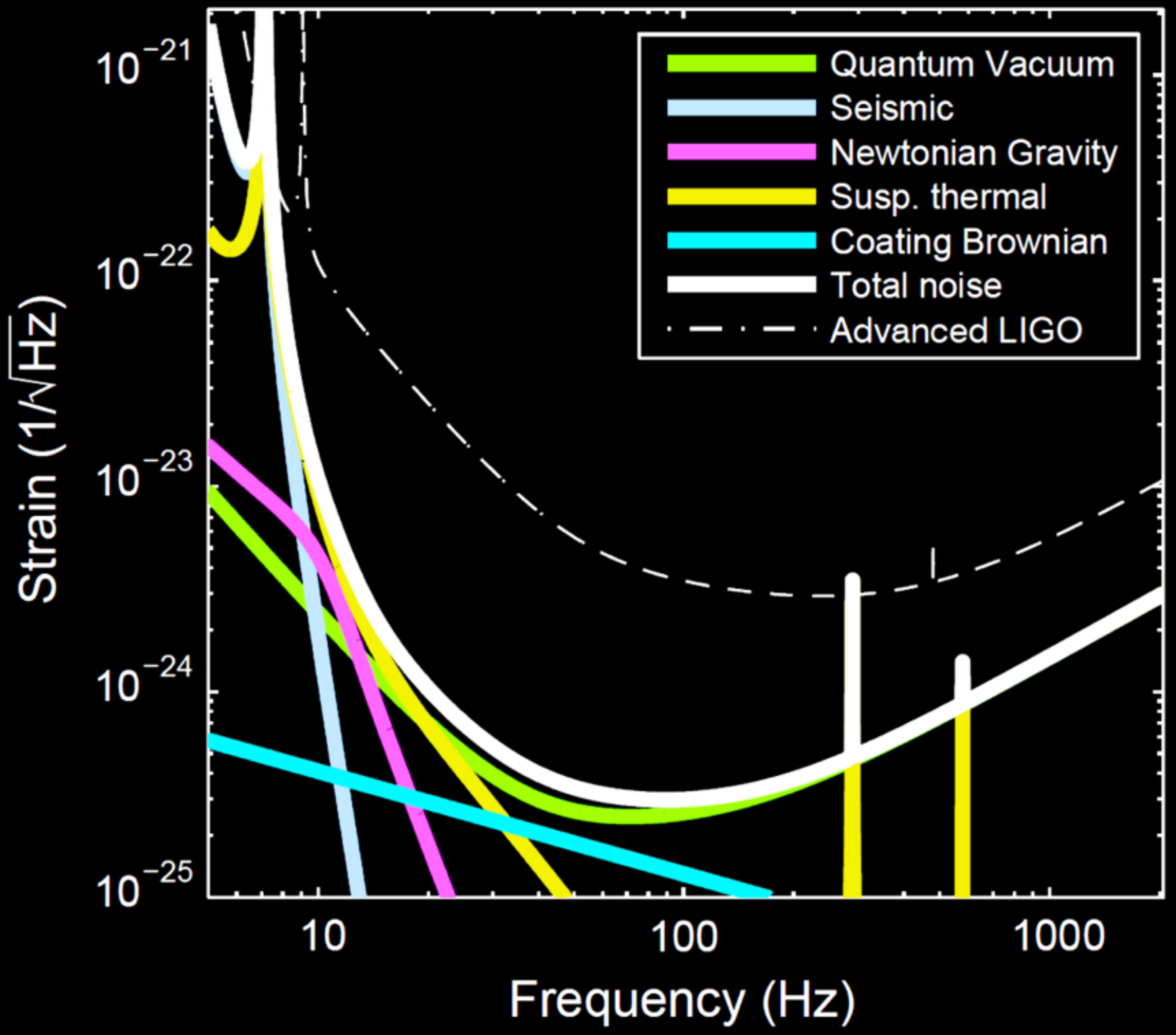
- Measured BBH coalescence rate is 9 - 240 Gpc^{-3} yr^{-1}
- O2 planned to start in Fall 2016
- Plan is a 6 month run split by a commissioning break
- Virgo planning on joining in Spring 2017

Abbott, ..., DAB, et al. arXix:1606.04856

Beyond Advanced LIGO

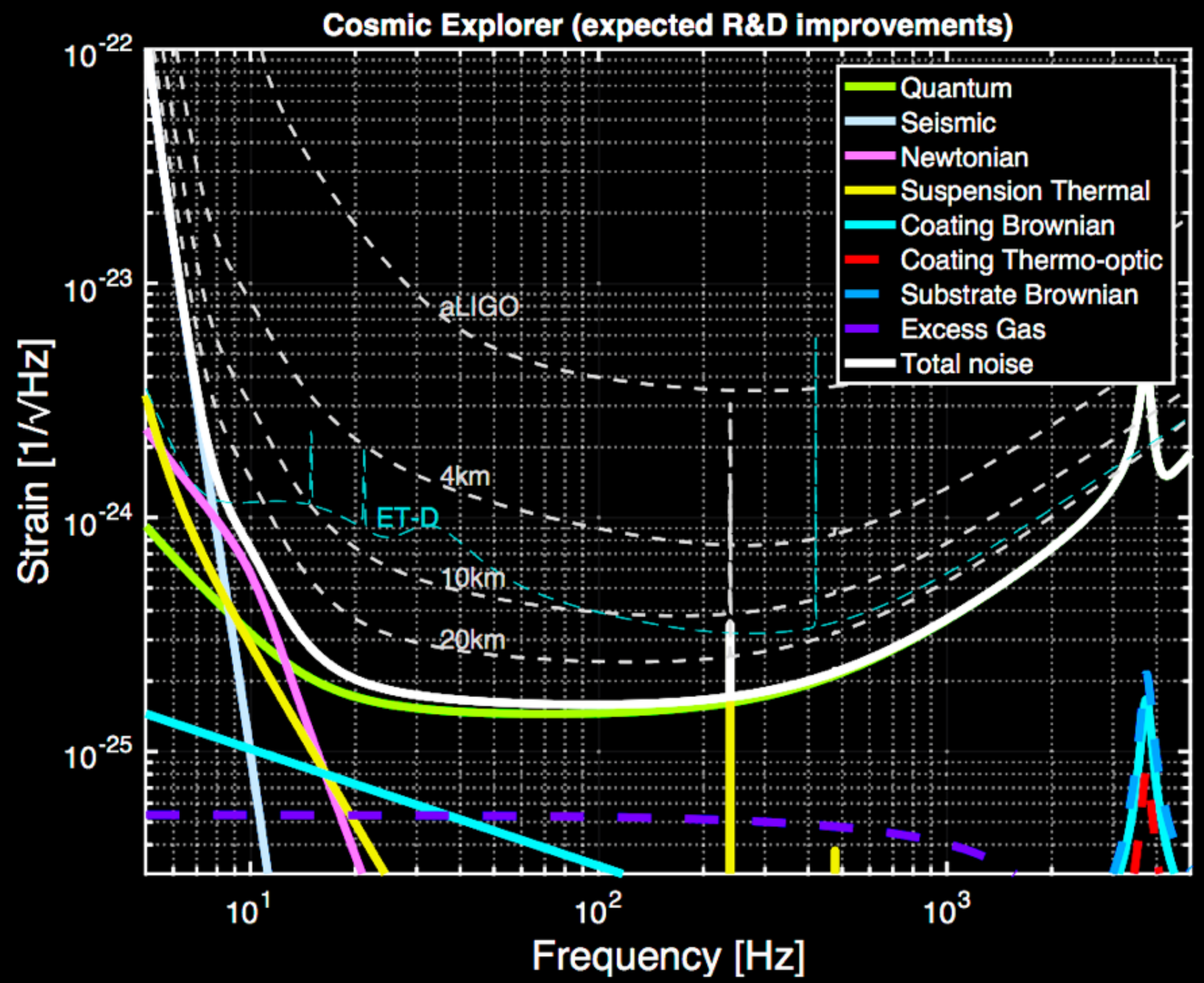


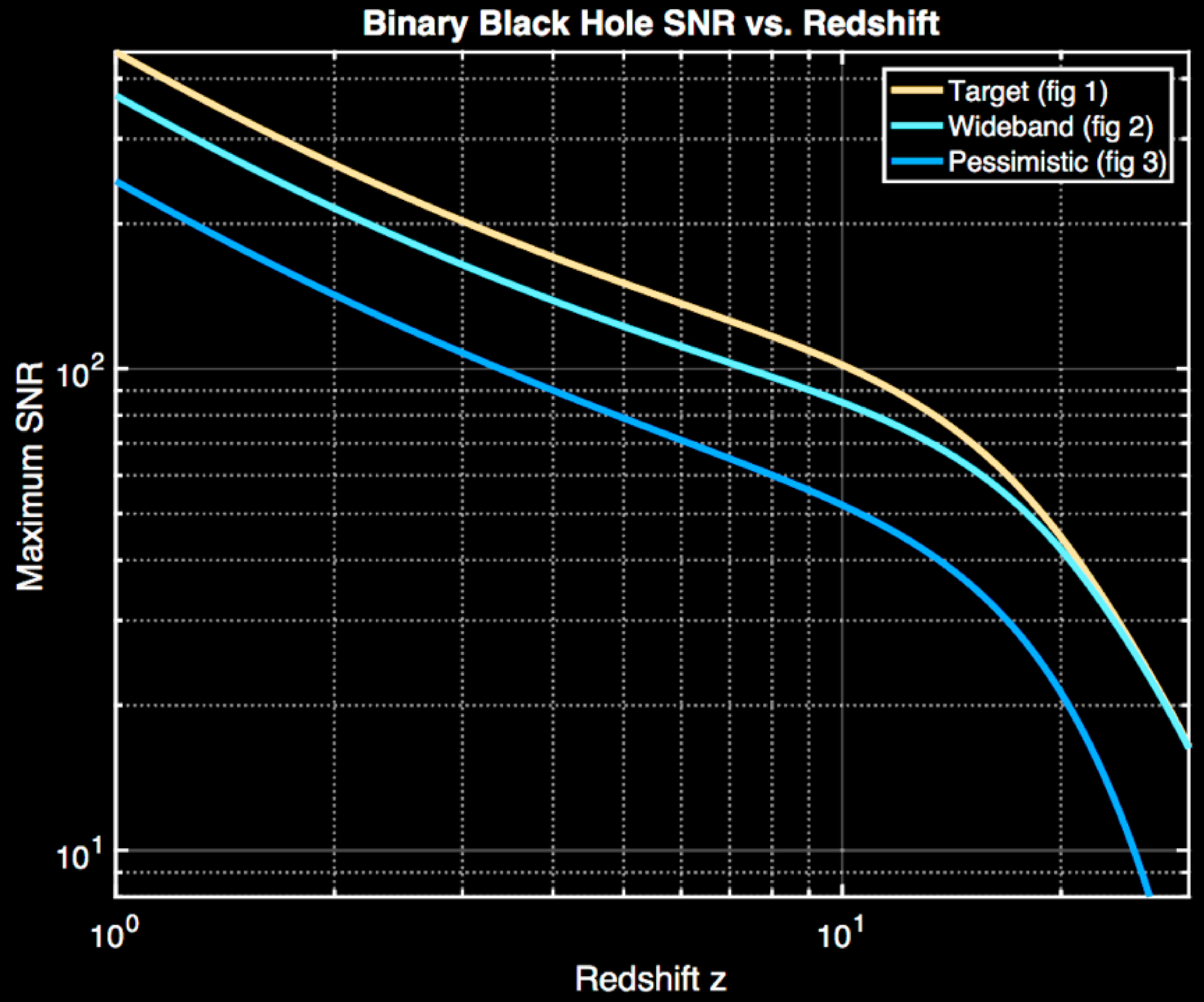
Miller et al. Phys. Rev. D 91, 062005 (2015)



Dwyer et al. Phys. Rev. D 91, 082001 (2015)

Cosmic Explorer





Evans, ..., DAB, et al. arXiv:1607.08697

Welcome to the era of gravitational-wave astronomy!