Searching for – and finding! gravitational waves

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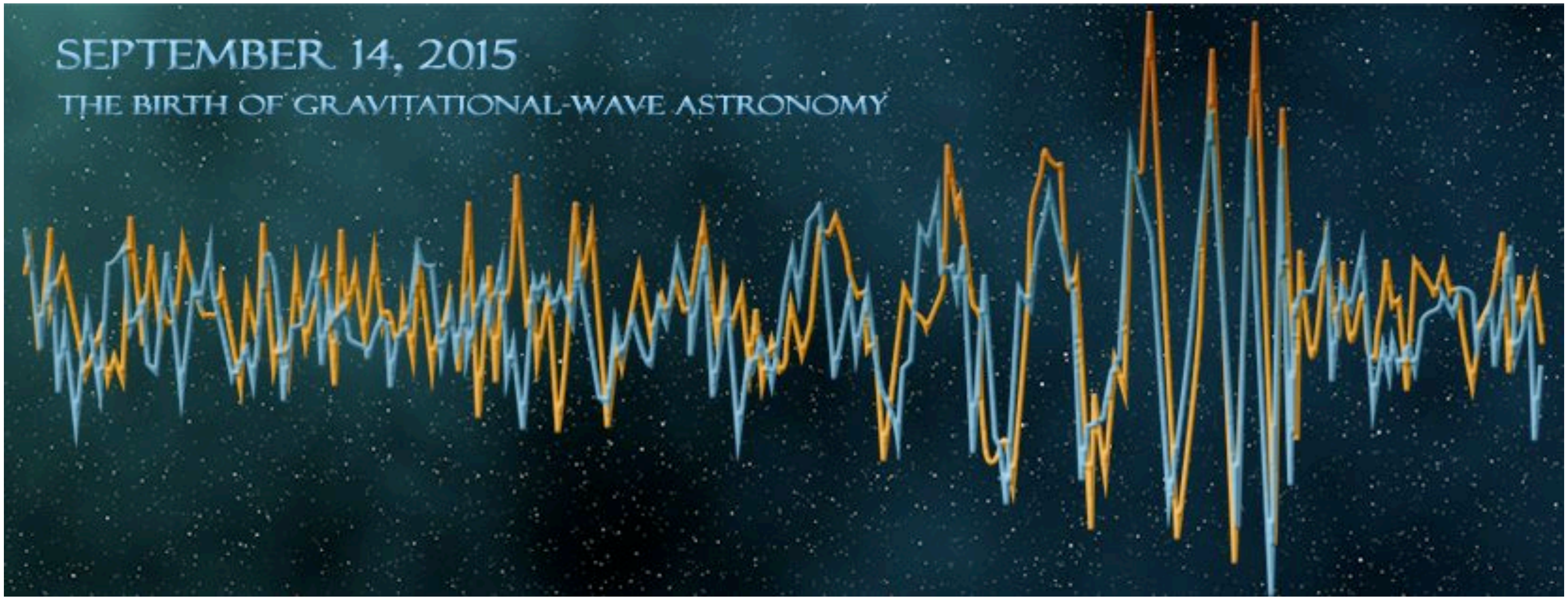
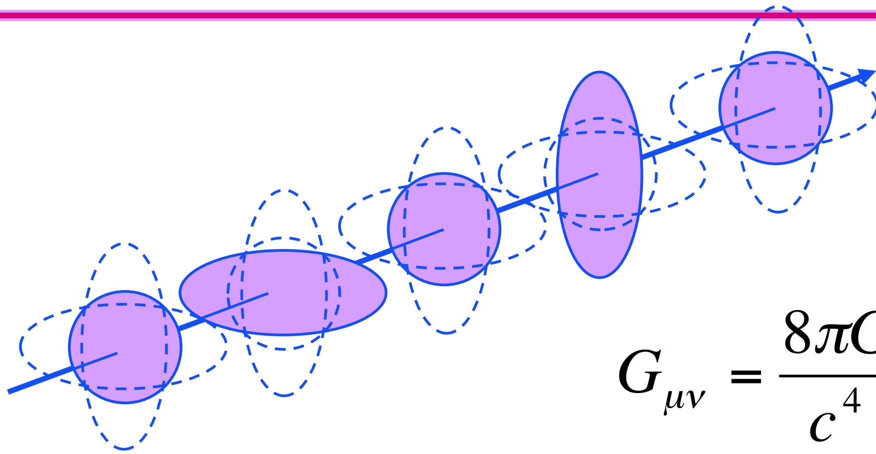
For the LIGO Scientific Collaboration and
the Virgo Collaboration



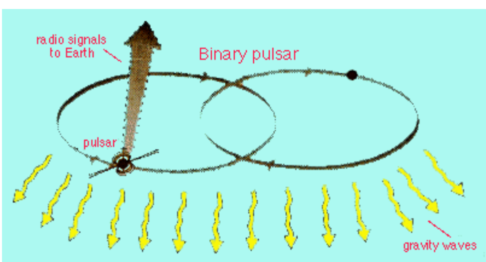
Gravitational waves



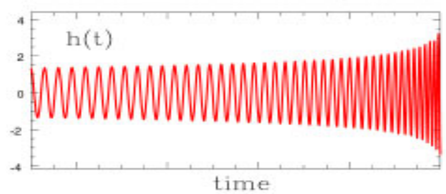
Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

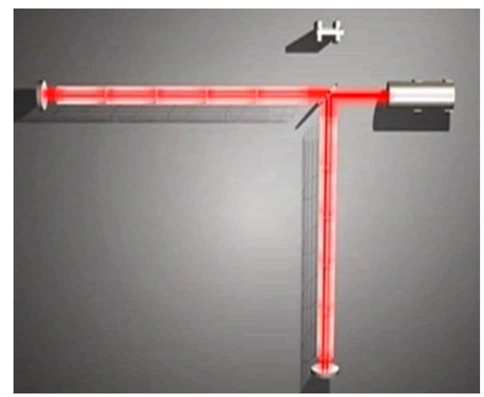
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \; (= 0 \text{ in vacuum})$$

$$h_{\mu\nu} \sim \frac{2G}{c^4 r} \ddot{I}_{\mu\nu} \qquad g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h = 2\frac{\Delta L}{L}$$



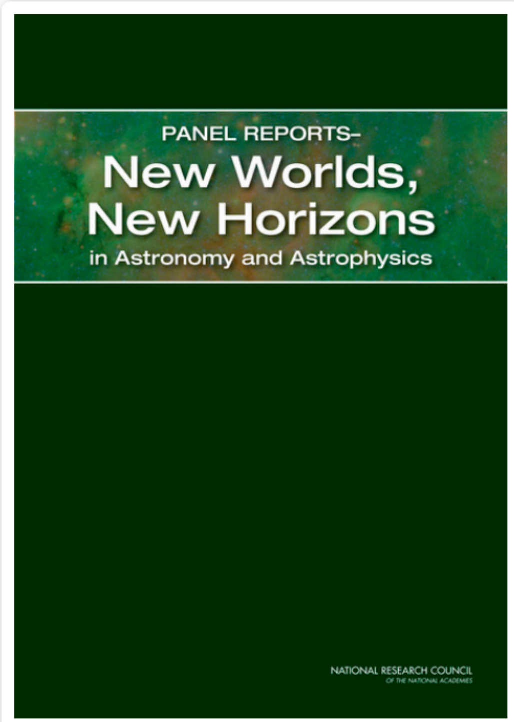
$$h_{\mu\nu} \sim \frac{R_1 R_2}{D r}$$





GWs from a NS-NS coalescence in the Virgo cluster has h ~ 10^{-21} near Earth, and happens ~once every 50 years.

New Worlds, New Horizons in 2011



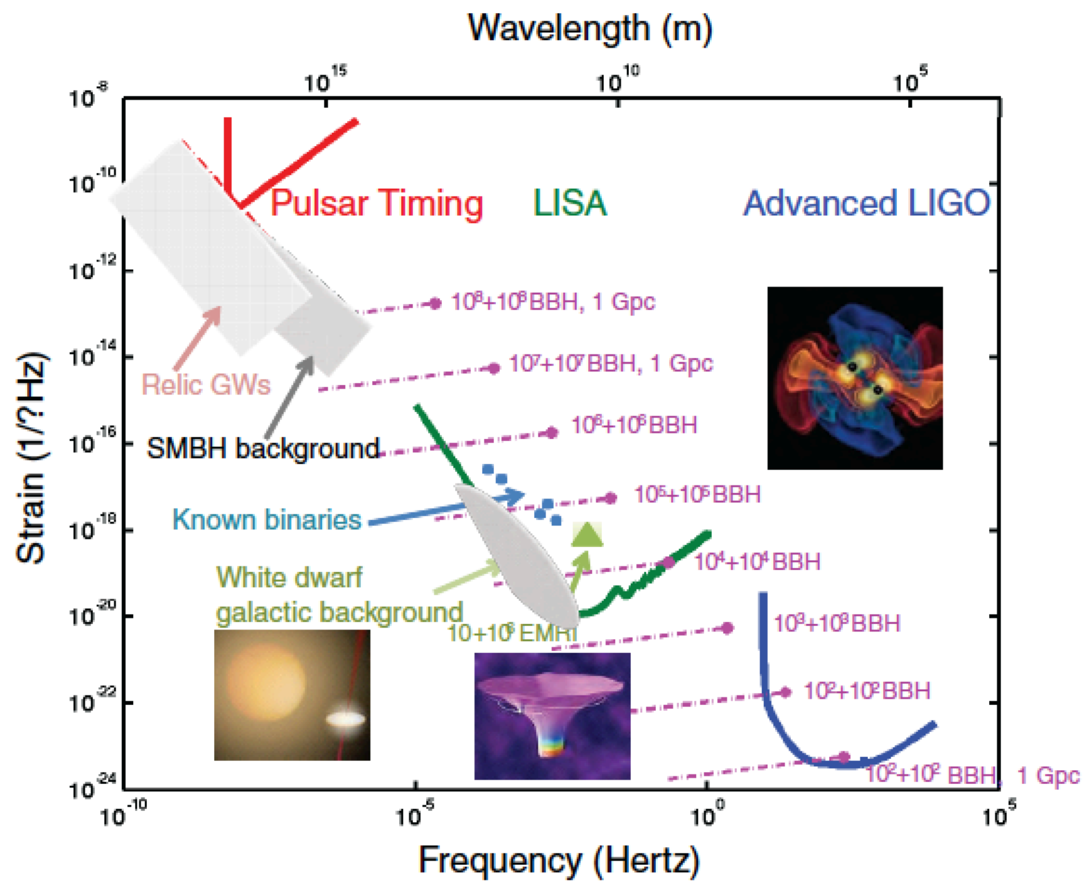
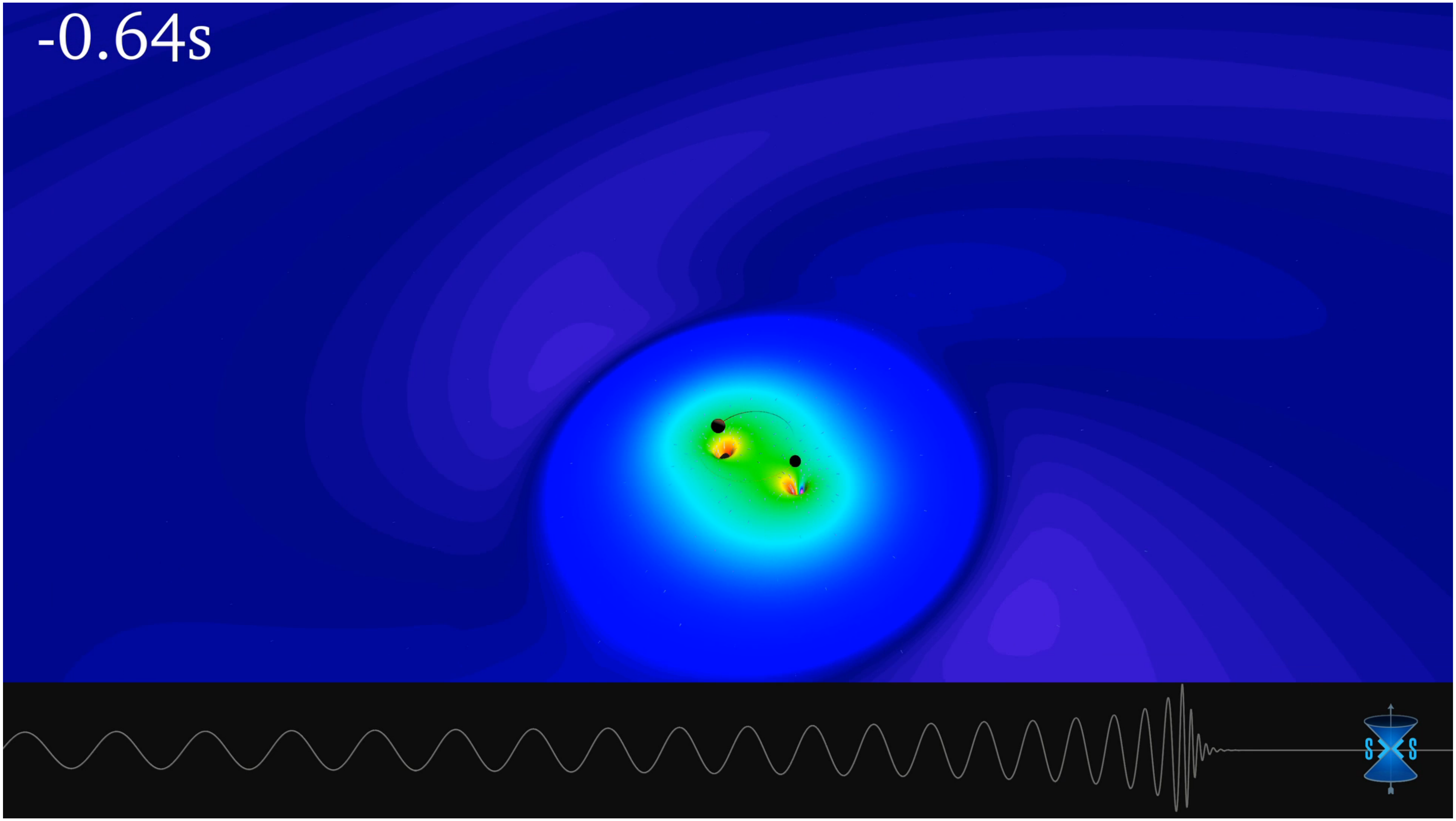


FIGURE 8.2 Strain amplitude sensitivity expected for pulsar timing (red), LISA (green), and Advanced LIGO (blue). The continuous curves show strain-noise-amplitude spectral density. The pulsar-timing sensitivity assumes the use of 20 pulsars with 100-ns timing residuals. The dashed magenta curves show the instantaneous strain of gravitational waves emitted by binary black hole (BBH) systems 1 Gpc away, evolving in frequency to the final coalescence frequency. In the LISA band, the figure shows an estimate of the unresolved background from galactic white-dwarf binary systems in shaded light green; the amplitude of some of the known binary systems; and a representative amplitude of the coalescence of an extreme-mass-ratio inspiral (EMRI) system. In the pulsar-timing band, the expected background is shown from relic gravitational waves (GWs) and from the unresolved signals of supermassive binary black hole systems.

A solution to Einstein's equations



Animation created by SXS, the Simulating eXtreme Spacetimes (SXS) project (http://www.black-holes.org)

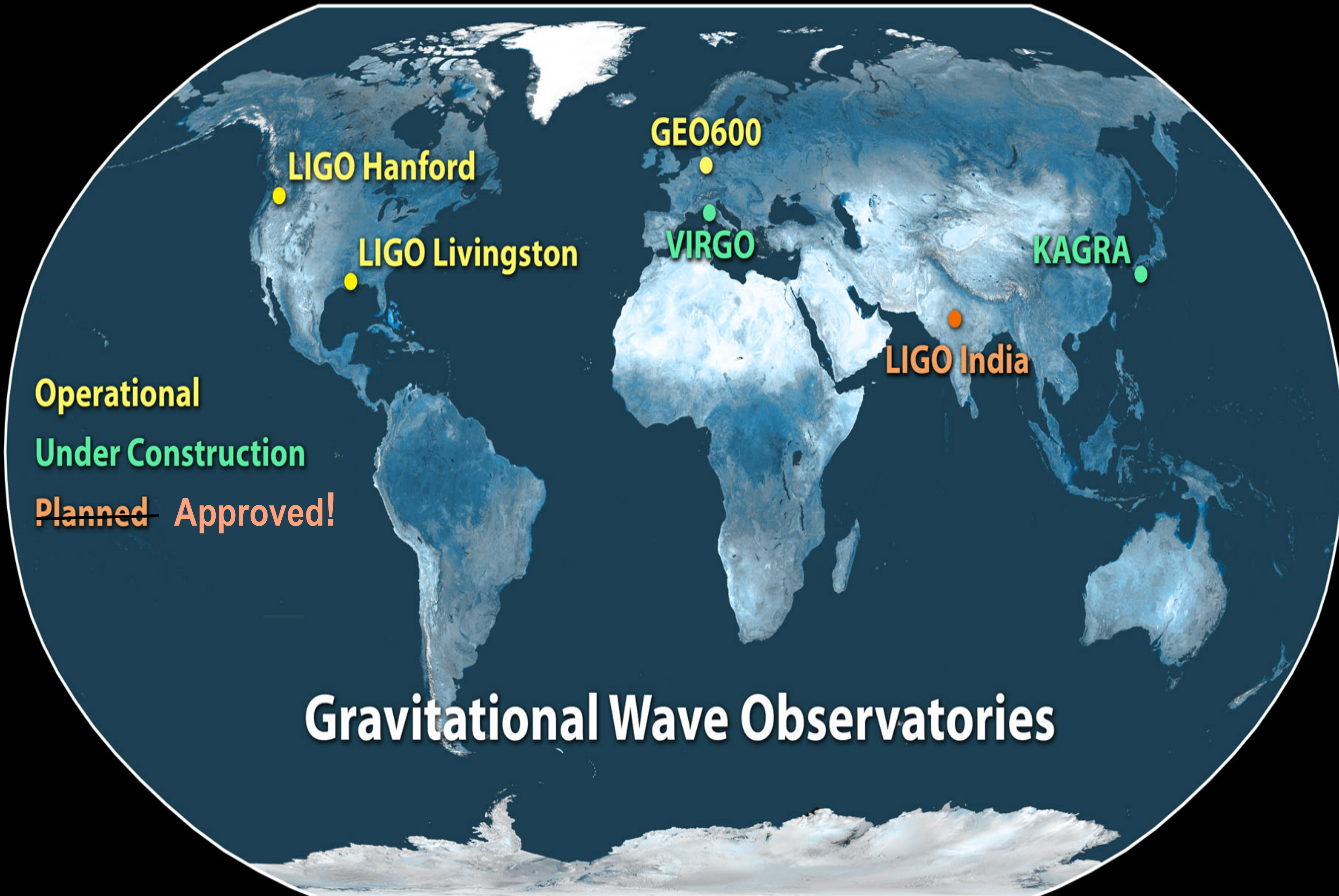
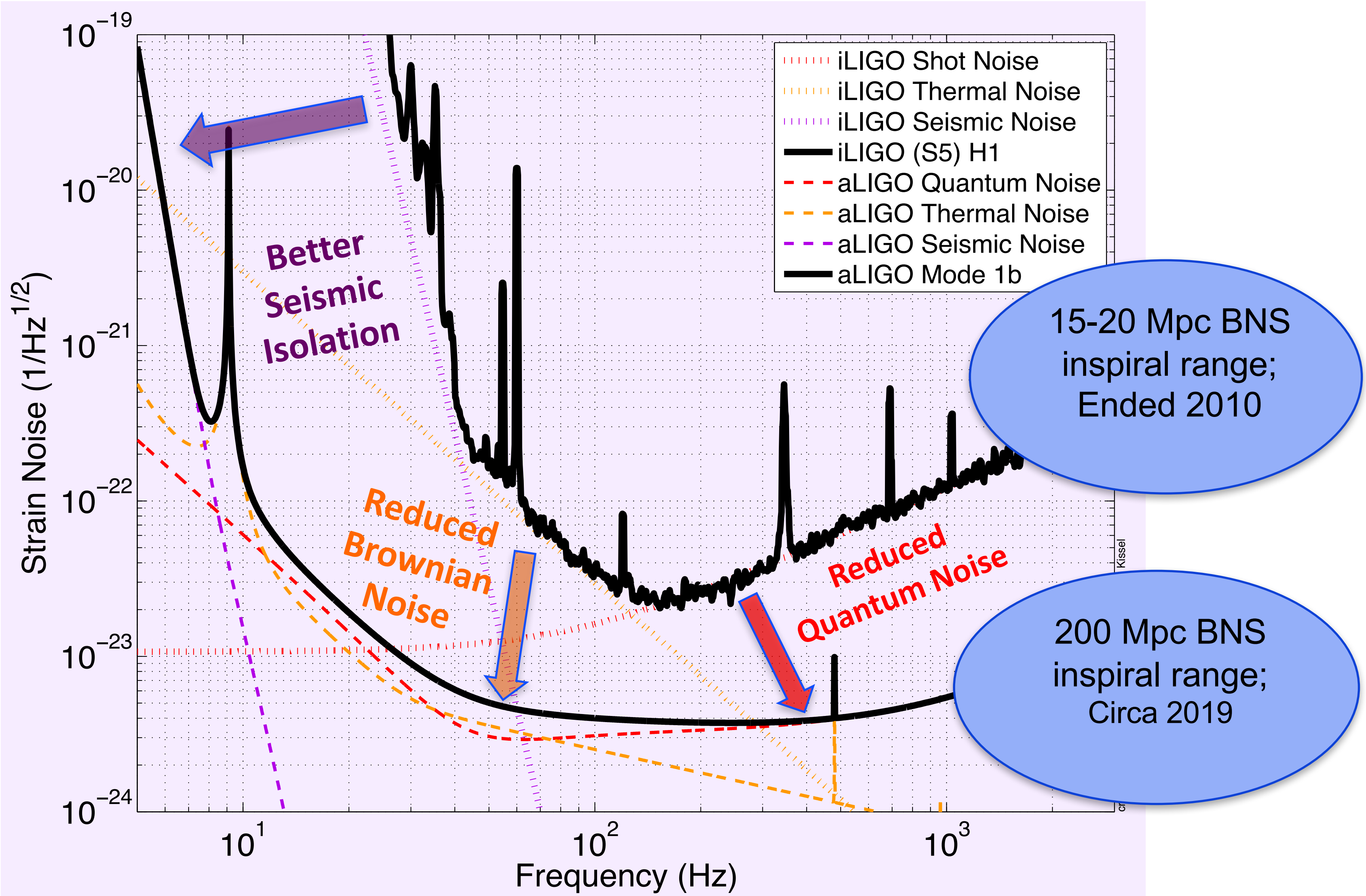
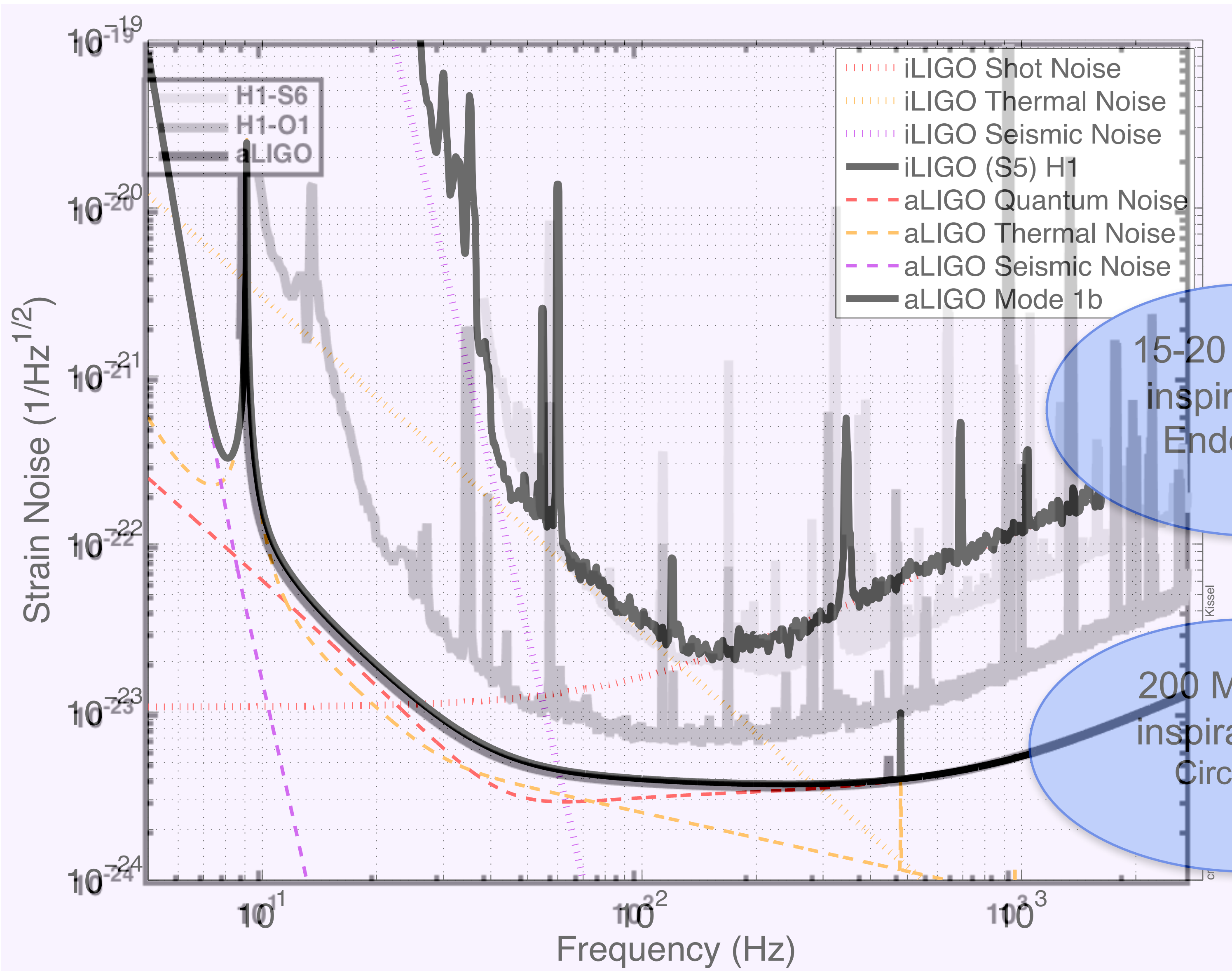


Image Credit: Caltech/MIT/LIGO Lab

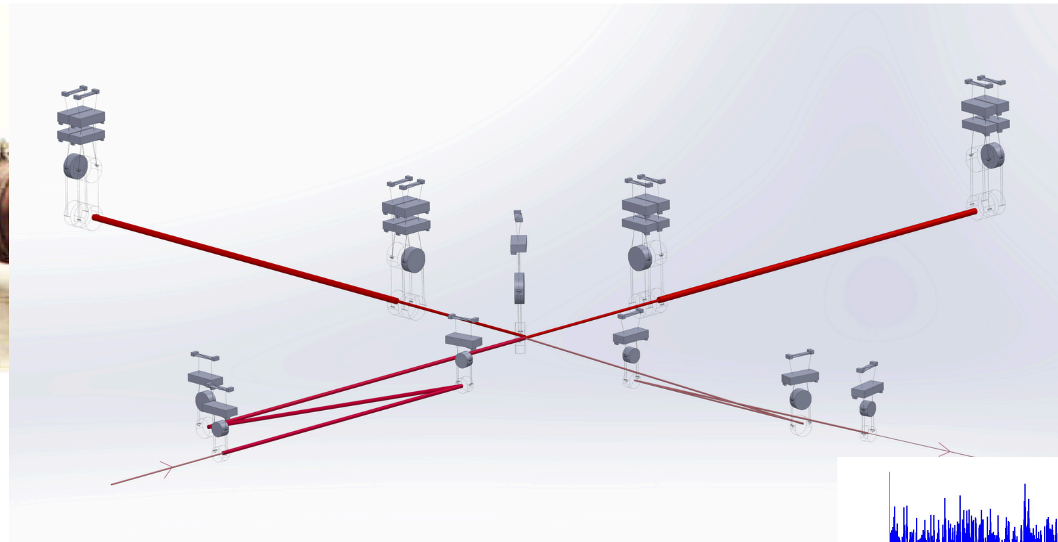
Initial (2001-2010) and advanced (2015+) LIGO

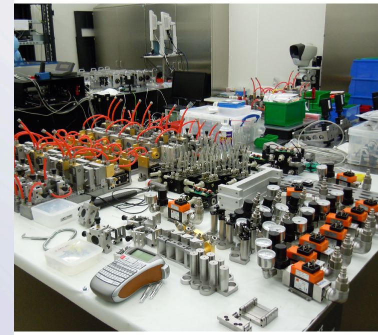


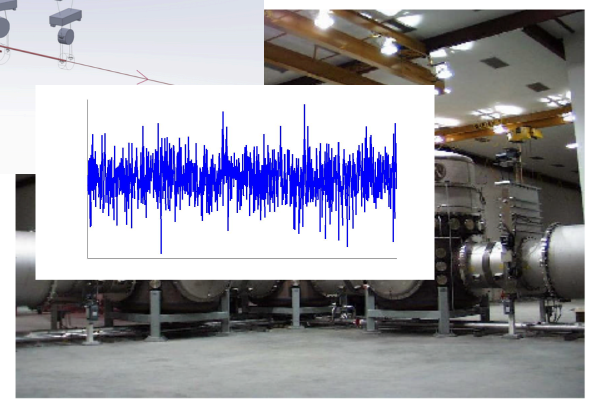
Initial (2001-2010) and advanced (2015+) LIGO

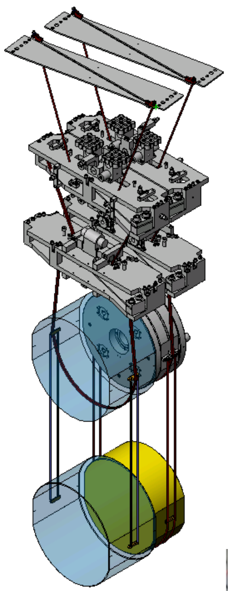


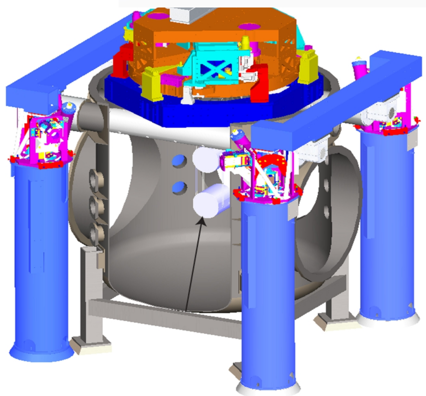
Advanced LIGO detectors

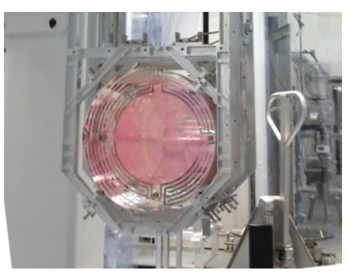




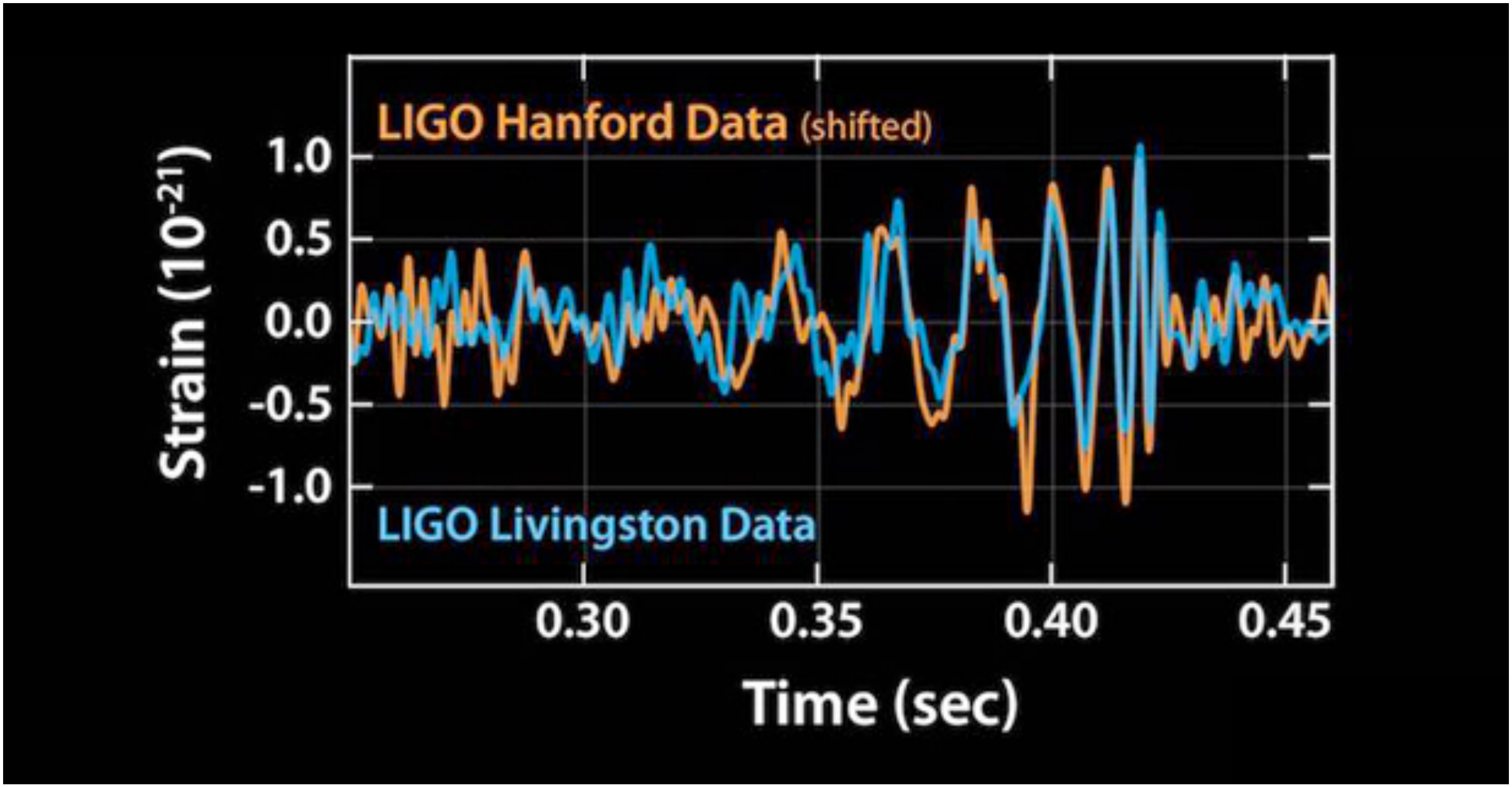








On Sept 14 2015…



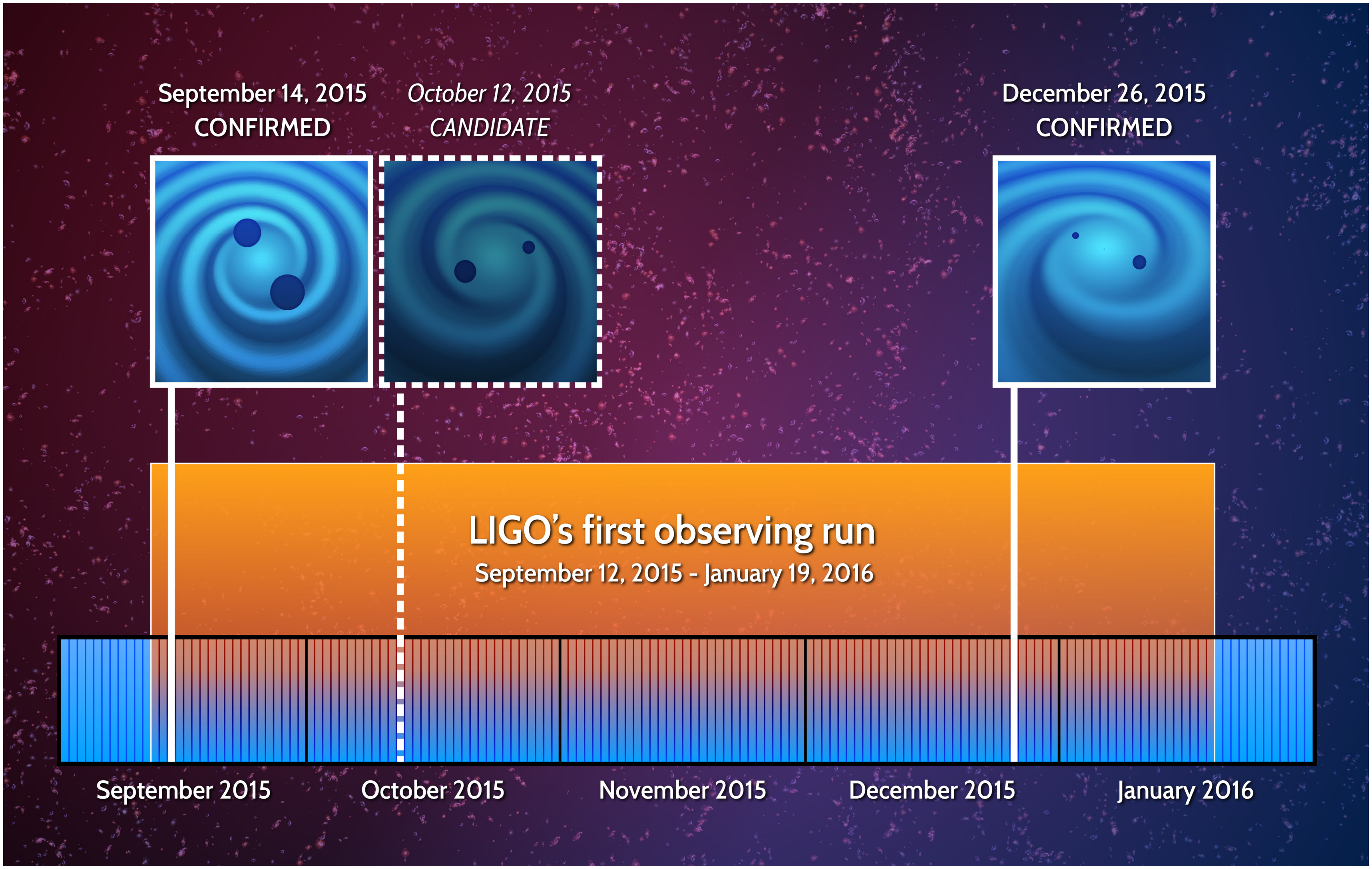


Image credit: LIGO

Filling in the black hole catalog

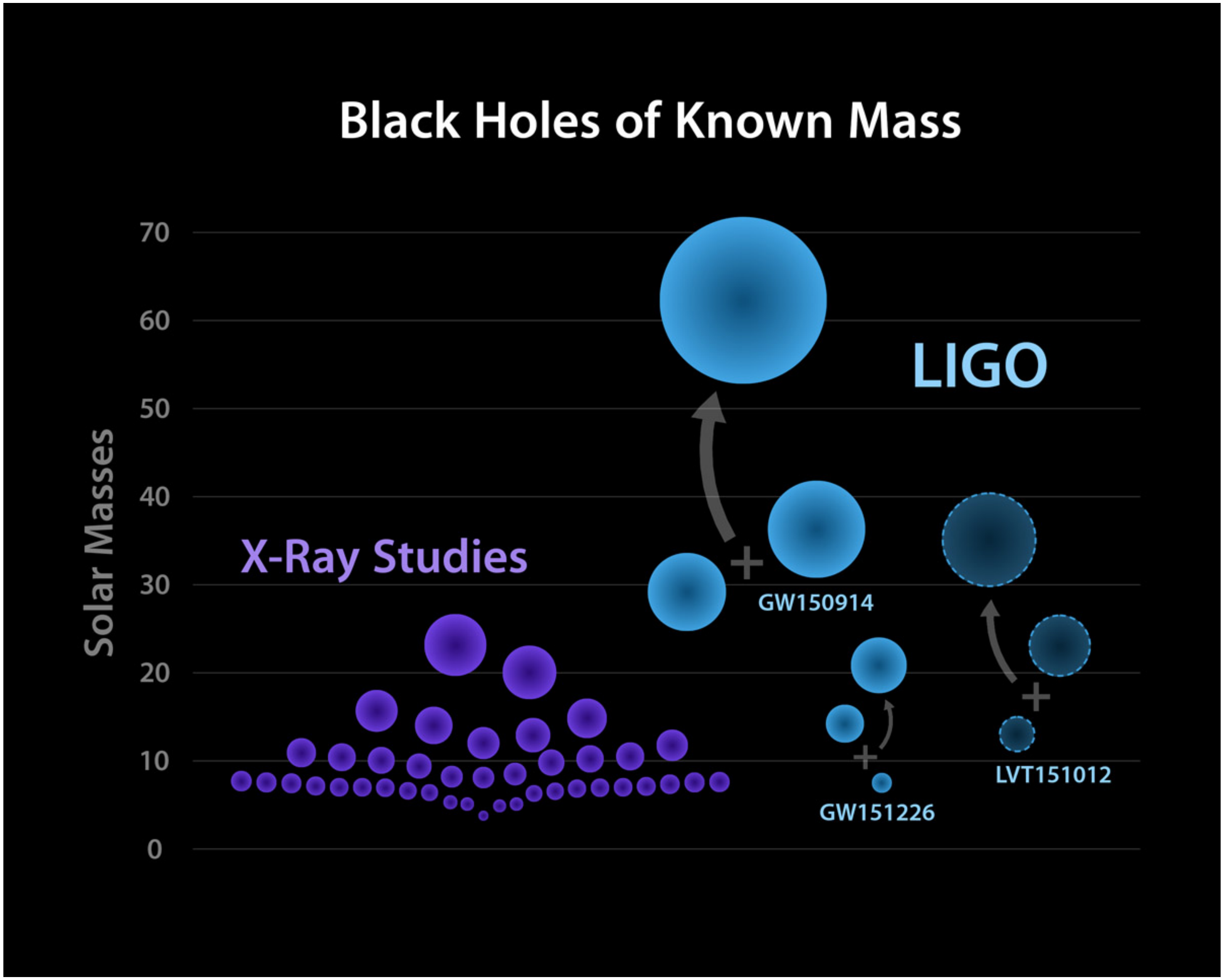
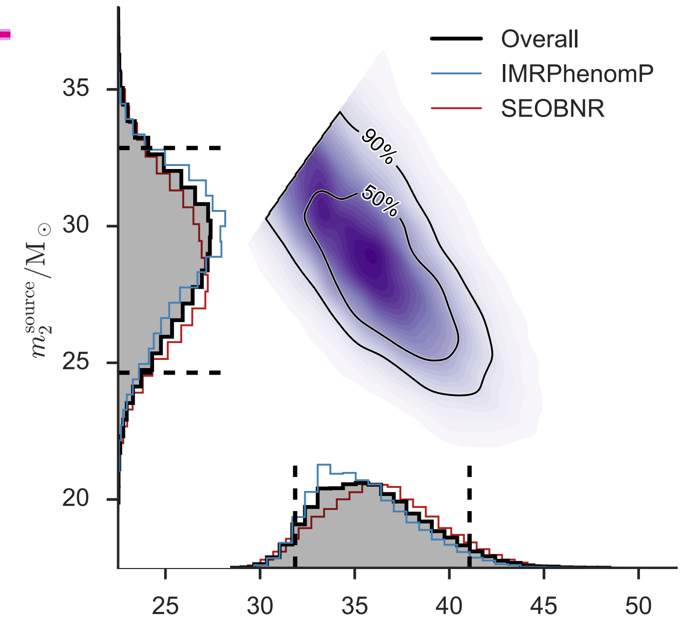
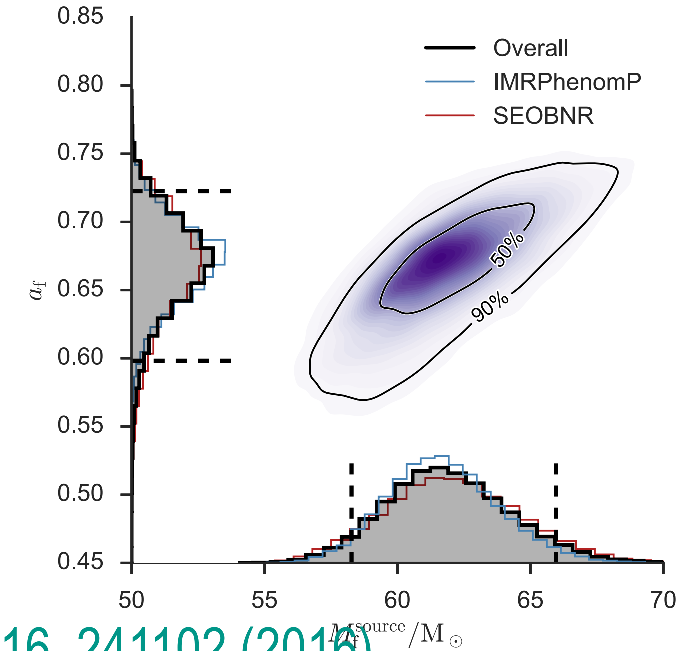
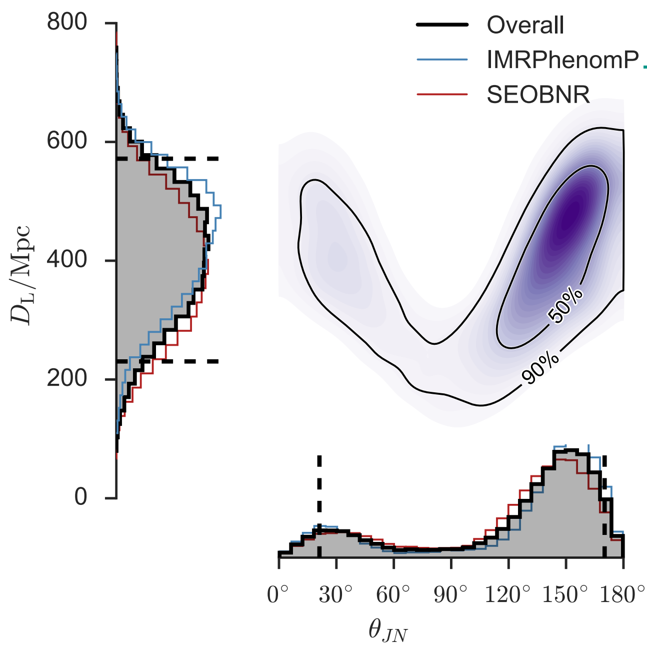


Image credit: LIGO

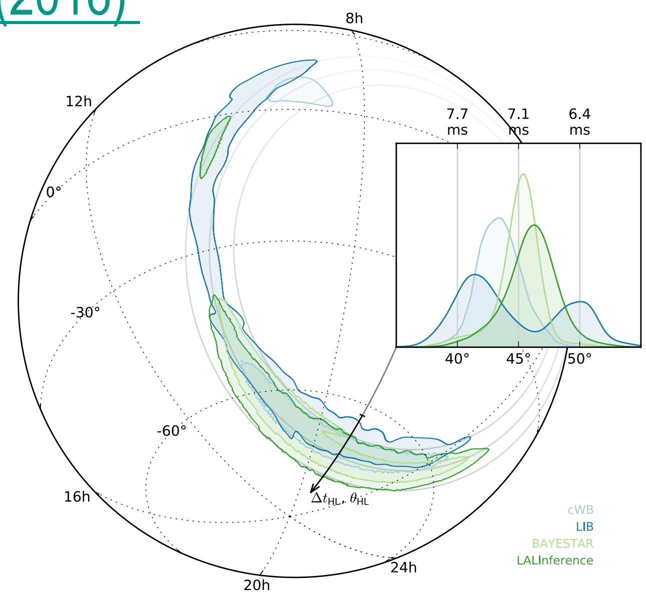
GW150914



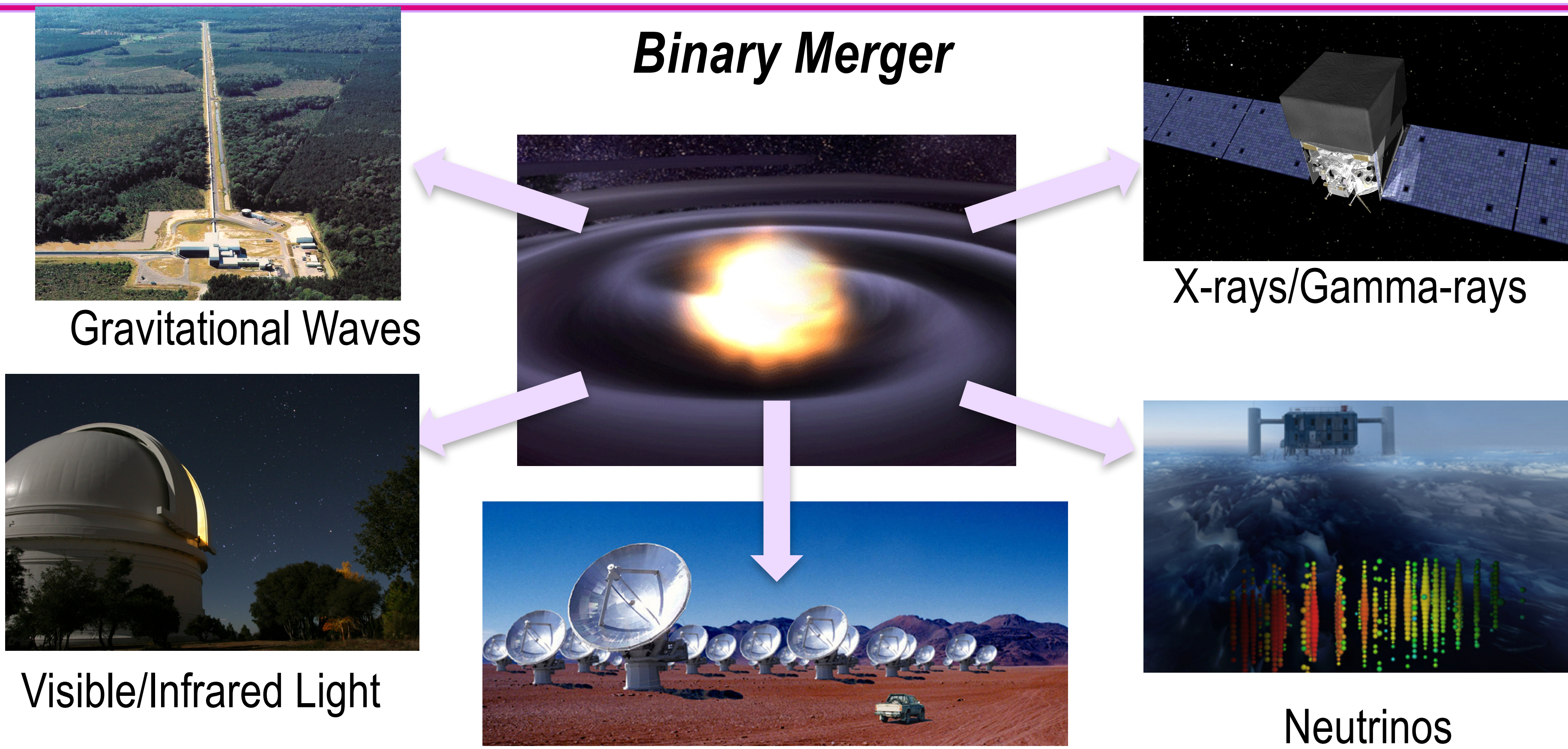




[Phys. Rev. Lett. 116, 241102 (2016)]



Multi-messenger Astronomy with Gravitational Waves



LOCALIZATION AND BROADBAND FOLLOW-UP OF THE GRAVITATIONAL-WAVE TRANSIENT GW150914

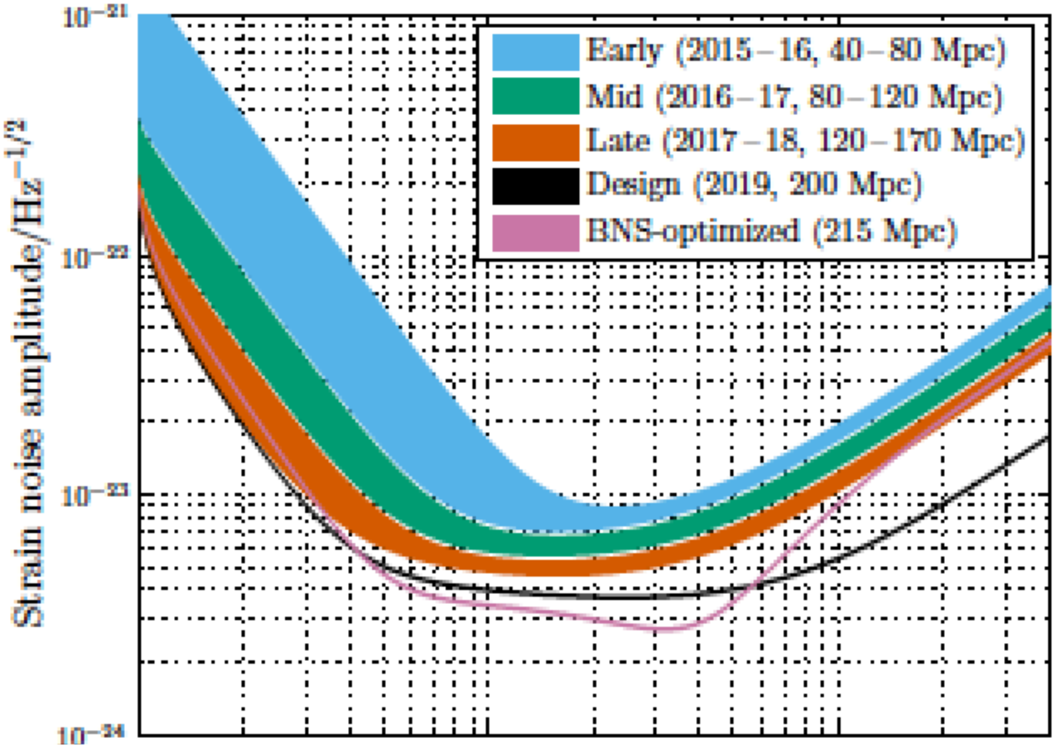
The LIGO Scientific Collaboration and the Virgo Collaboration,
The Australian Square Kilometer Array Pathfinder (ASKAP) Collaboration, The BOOTES Collaboration,
The Dark Energy Survey and the Dark Energy Camera GW-EM Collaborations, The *Fermi* GBM Collaboration,
The *Fermi* LAT Collaboration, The GRAvitational Wave Inaf TeAm (GRAWITA), The *INTEGRAL* Collaboration,
The Intermediate Palomar Transient Factory (iPTF) Collaboration, The InterPlanetary Network,
The J-GEM Collaboration, The La Silla–QUEST Survey, The Liverpool Telescope Collaboration,
The Low Frequency Array (LOFAR) Collaboration, The MASTER Collaboration, The MAXI Collaboration,
The Murchison Wide-field Array (MWA) Collaboration, The Pan-STARRS Collaboration,
The PESSTO Collaboration, The Pi of the Sky Collaboration, The SkyMapper Collaboration,
The *Swift* Collaboration, The TAROT, Zadko, Algerian National Observatory, and C2PU Collaboration,
The TOROS Collaboration, and The VISTA Collaboration

Living Rev. Relativity, **19**, (2016), 1
DOI 10.1007/lrr-2016-1

LIVING REVIEWS in relativity

Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo

Abbott, B. P. et al.
The LIGO Scientific Collaboration and the Virgo Collaboration
(The full author list and affiliations are given at the end of paper.)
email: lsc-spokesperson@ligo.org, virgo-spokesperson@ego-gw.it



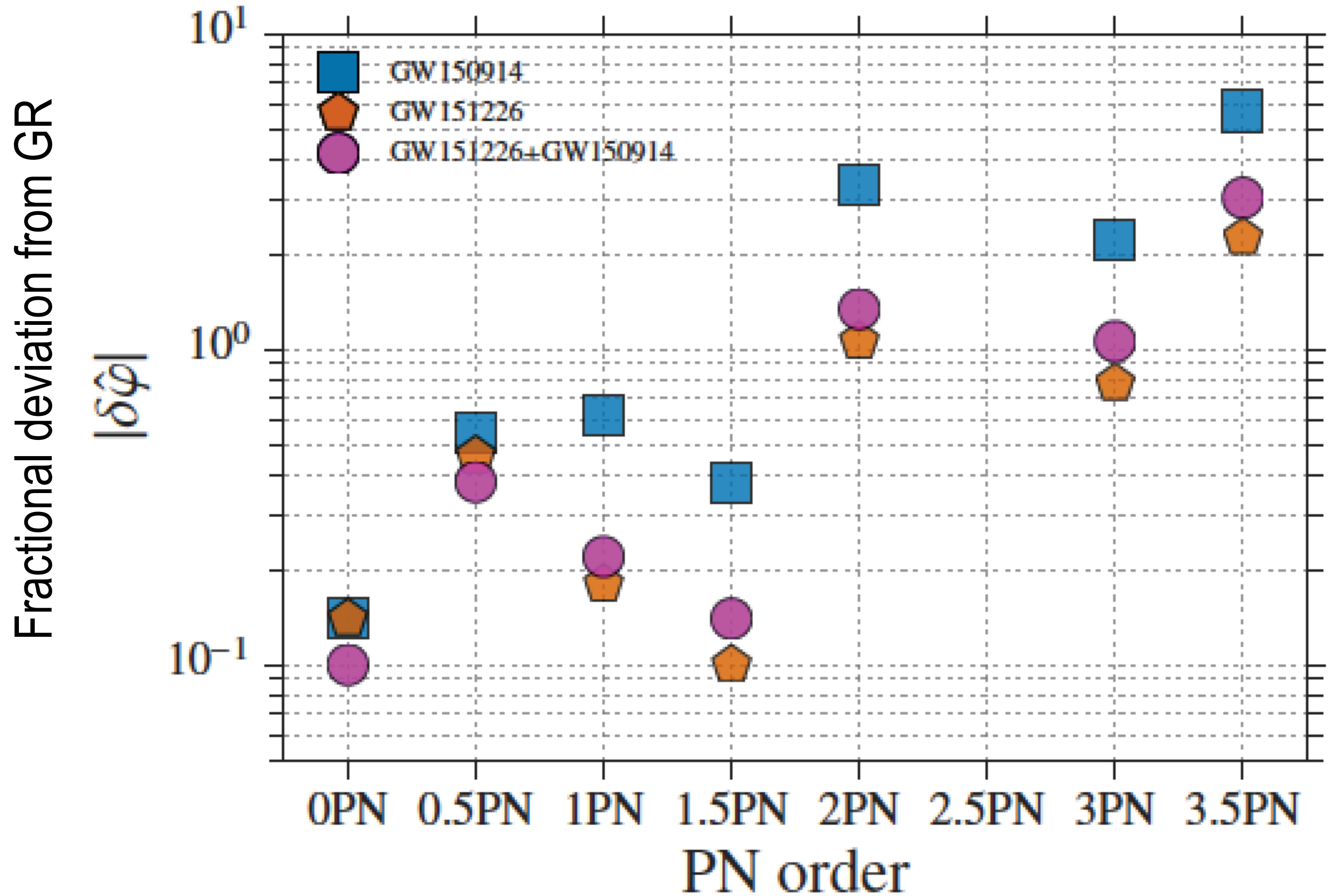
2015 – 2016 (O1) A four-month run (beginning 18 September 2015 and ending 12 January 2016) with the two-detector H1L1 network at early aLIGO sensitivity (40 – 80 Mpc BNS range).

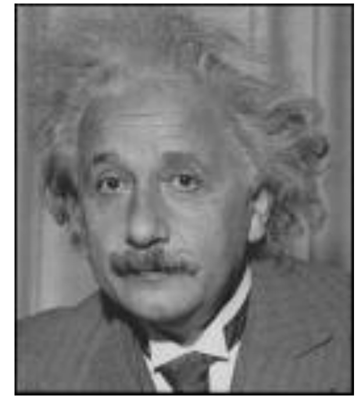
2016 – 2017 (O2) A six-month run with H1L1 at 80 – 120 Mpc and V1 at 20 – 60 Mpc.

2017 – 2018 (O3) A nine-month run with H1L1 at 120 – 170 Mpc and V1 at 60 – 85 Mpc.

2019+ Three-detector network with H1L1 at full sensitivity of 200 Mpc and V1 at 65 – 115 Mpc.

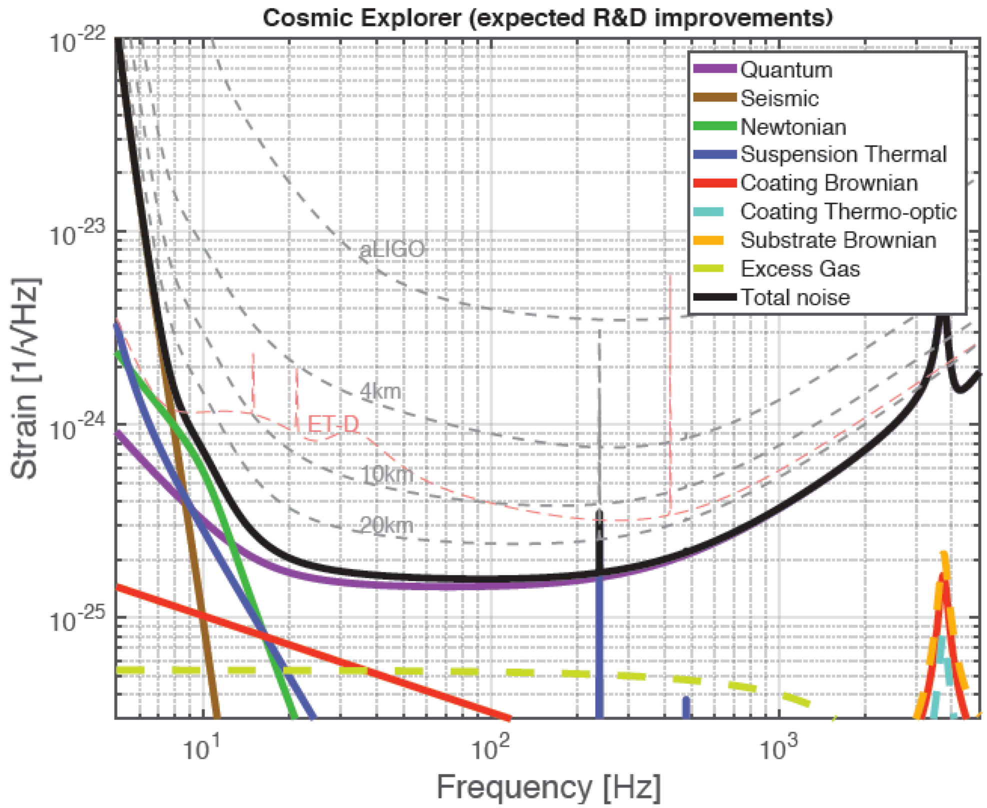
Testing General Relativity



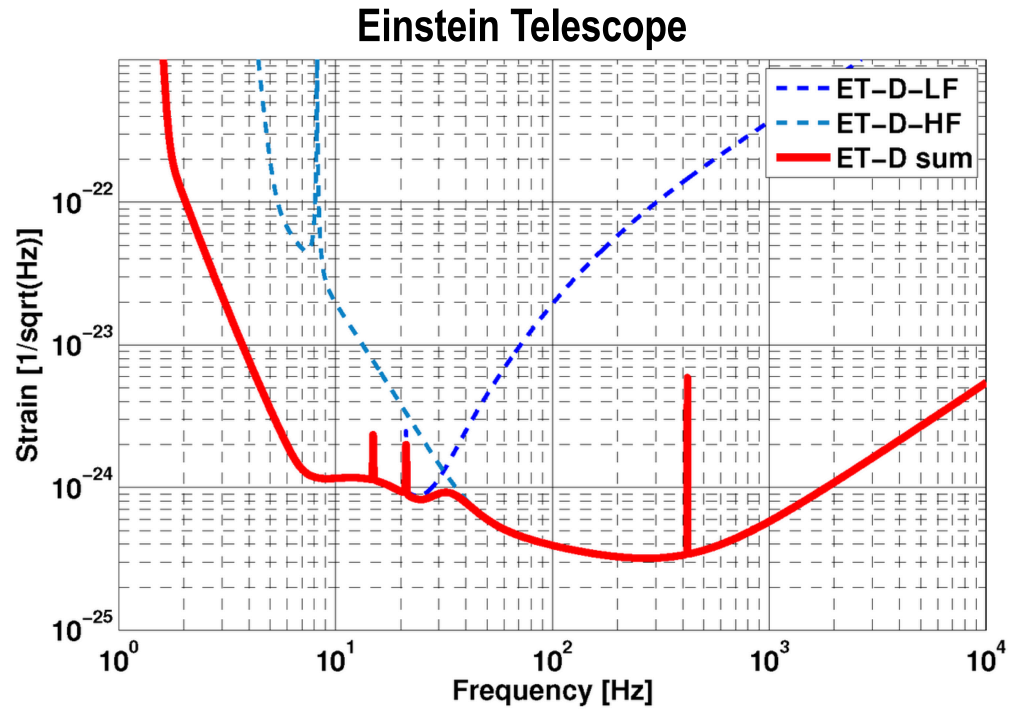


Phys. Rev. Lett. 116, 221101 (2016)

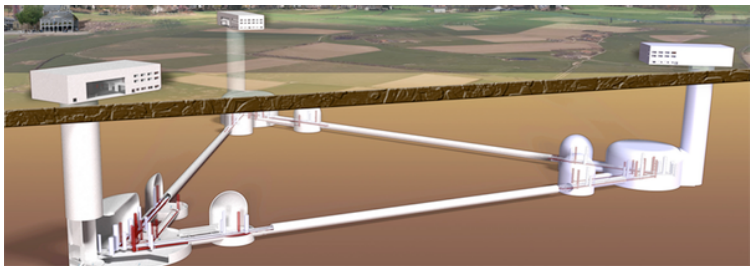
The future: 3rd generation detectors



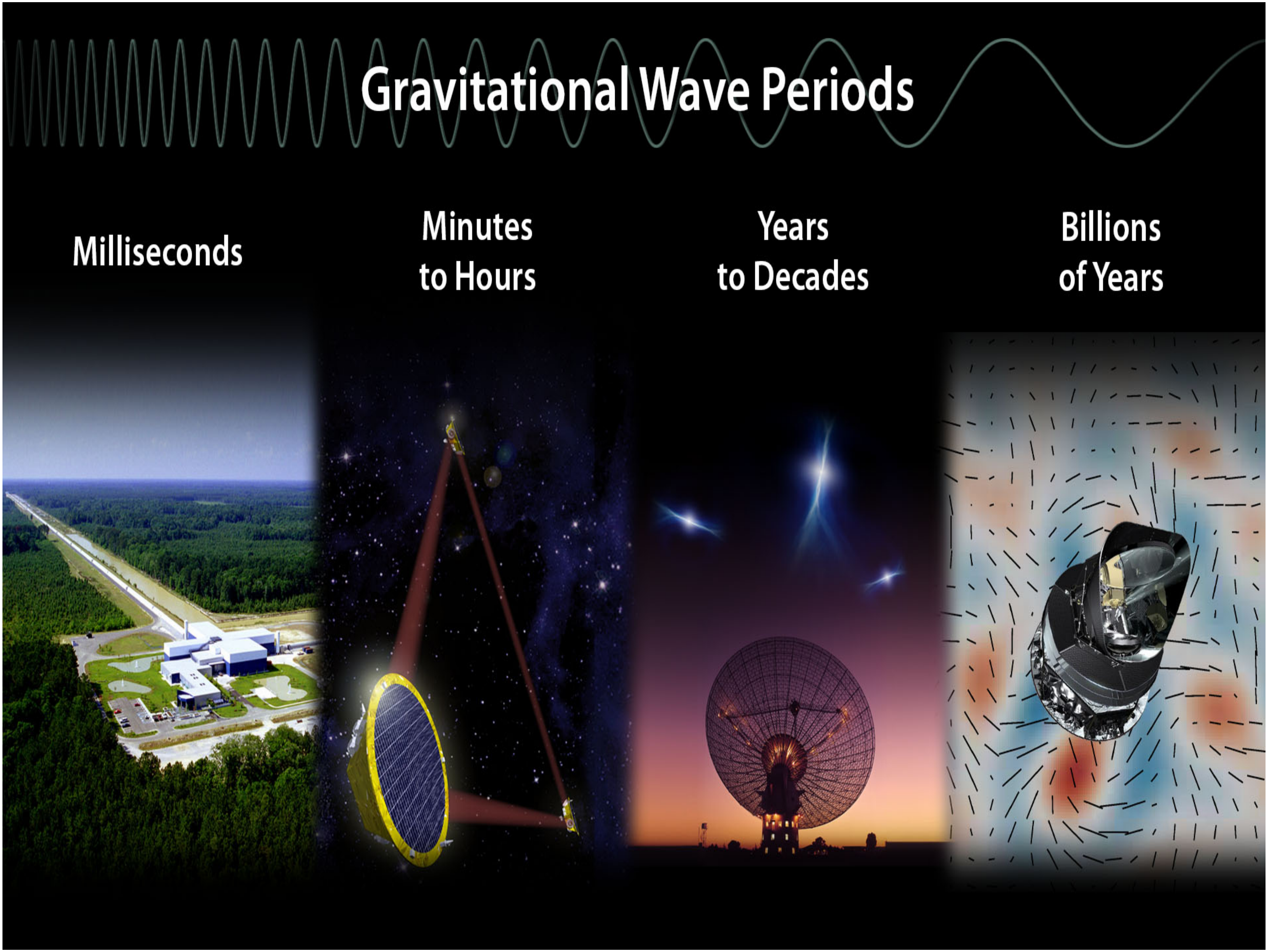
arXiv:1607.08697



S.Hild et al., Classical and Quantum Gravity, 28 094013, 2011



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


Gravitational Wave Periods
Milliseconds
Minutes
to Hours
Years
to Decades
Billions
of Years

Perhaps more than just complementary science!

M. Colpi, A. Sesana *Gravitational wave surces*

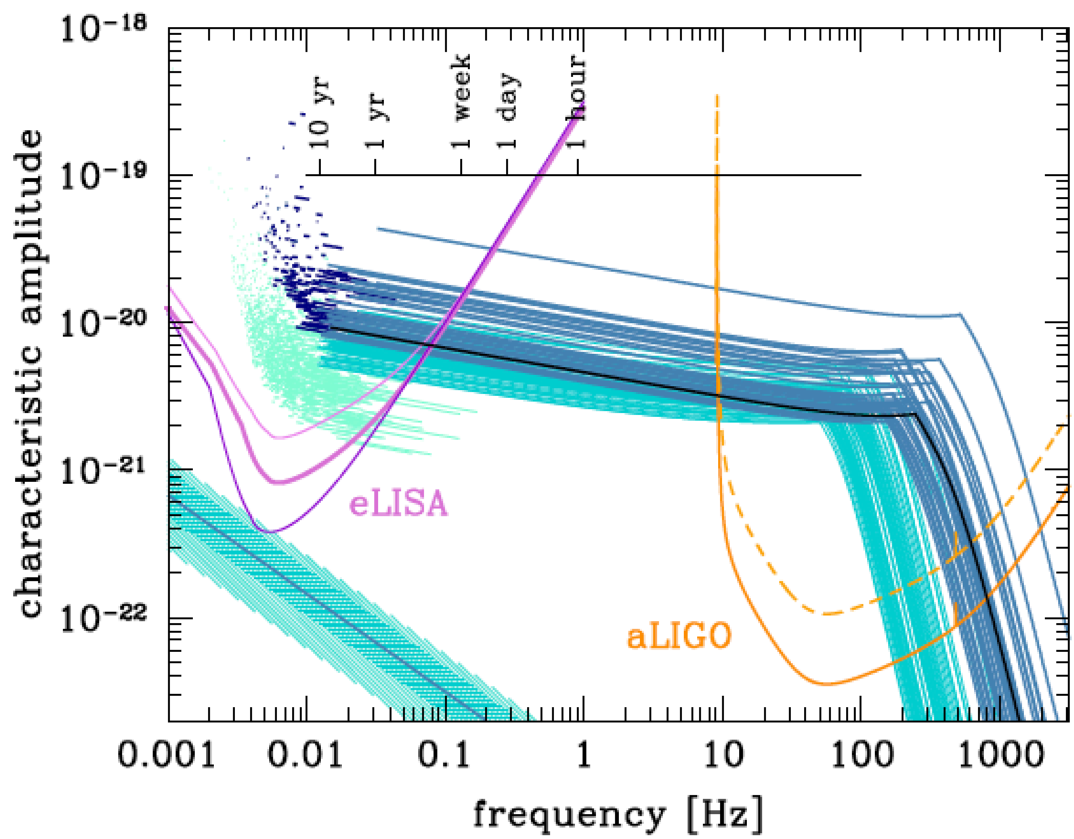


Figure 34: Multi-band gravitational wave astronomy of (BH*,BH*) binaries, adapted from.[174] Plotted is the dimensionless characteristic amplitude versus frequency as in Figure 33. The violet lines are the sensitivity curves of three eLISA configurations; from top to bottom N2A1, N2A2, N2A5.[175] The orange lines are the current (dashed) and design (solid) Advanced LIGO sensitivity curves.[172] Blue lines represent tracks of a sample of (BH*,BH*) binaries. The

Thanks!

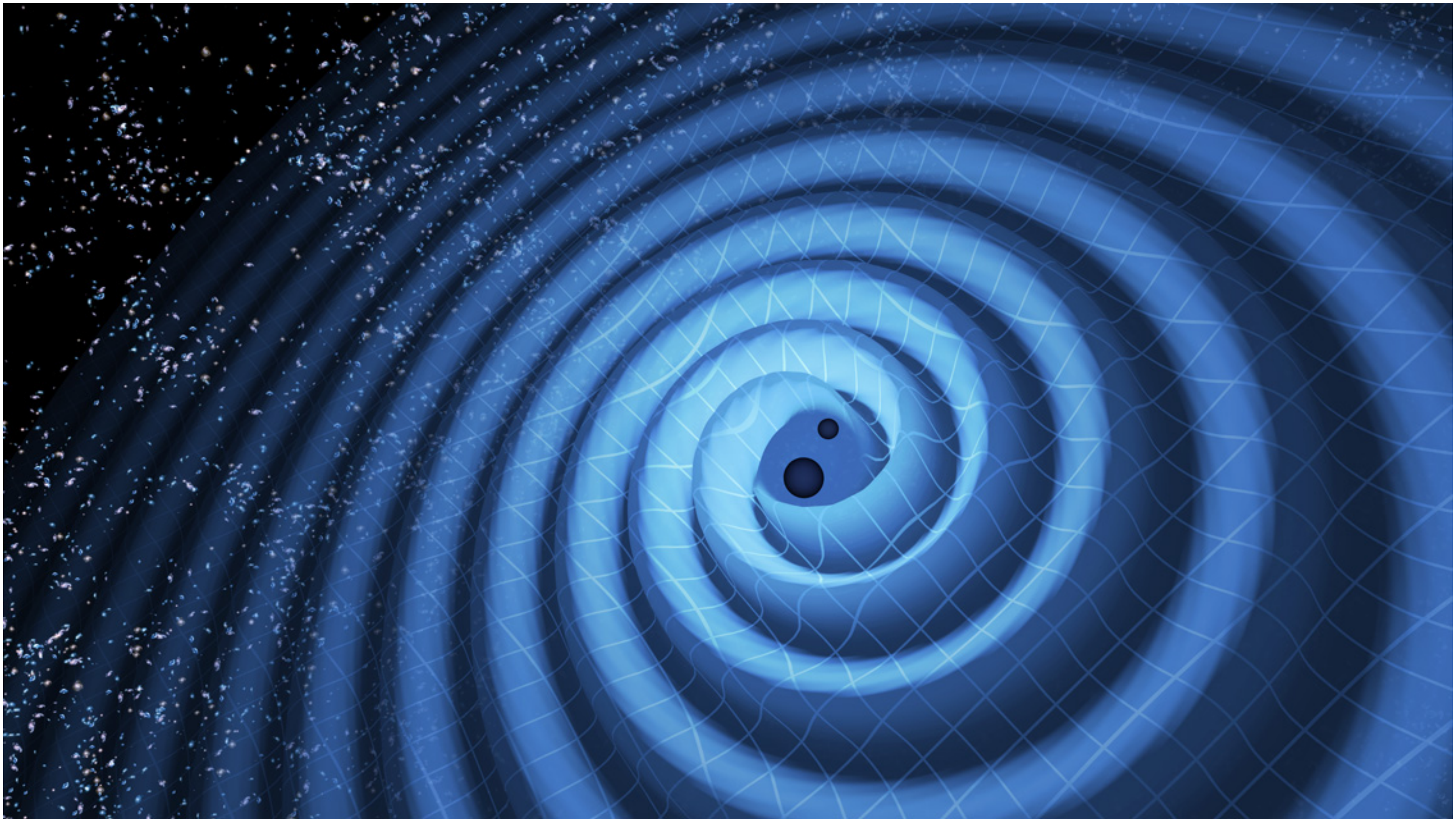


Image credit: LIGO/T. Pyle

www.ligo.org

Gravity’s music