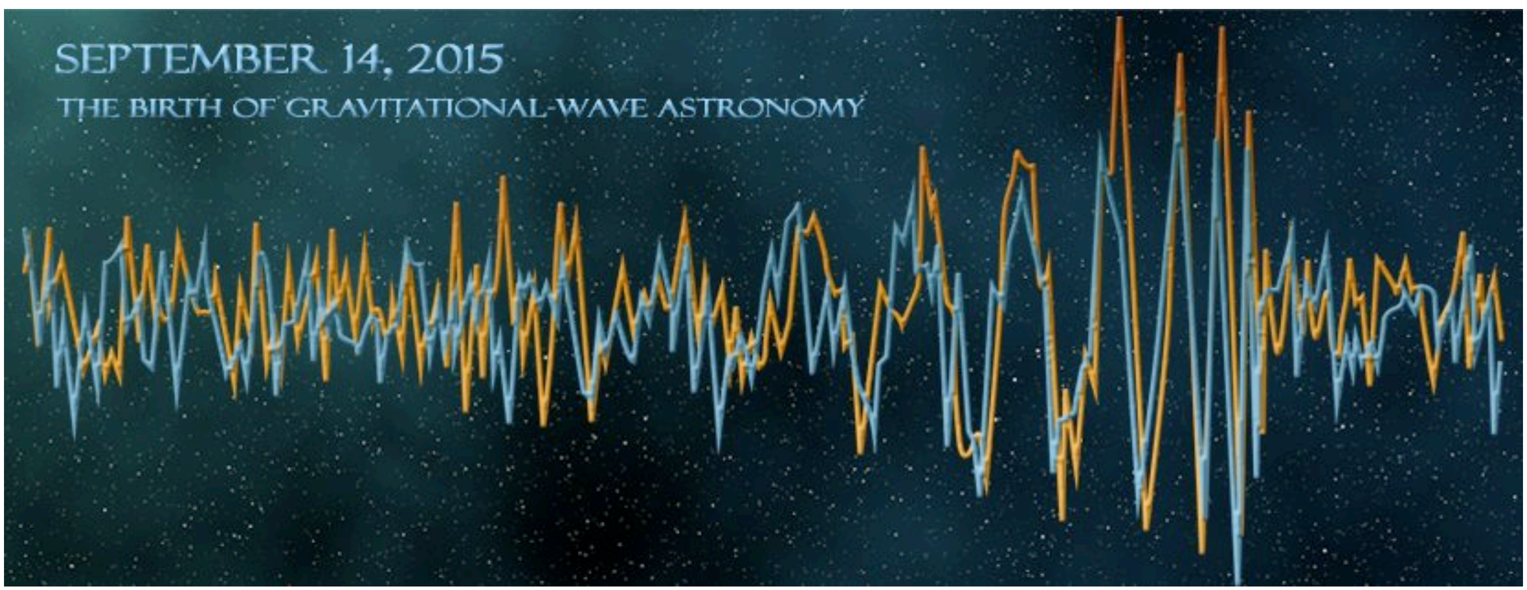
Searching – and finding! gravitational waves

Gabriela González
Louisiana State University

For the LIGO Scientific Collaboration and the Virgo Collaboration

AAS meeting, San Diego, CA

June 15, 2016



LIGO-G1601317

PRL 116, 061102 (2016)

PHYSICAL REVIEW LETTERS

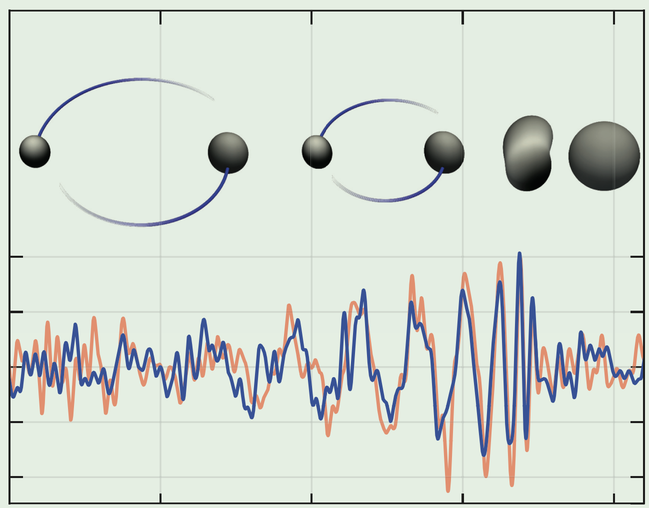
week ending
12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)



Published by
American Physical Society™

APS physics

Volume 116, Number 6

PRL 116, 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

(Accepted for publication, in proofs) PHYSICAL REVIEW LETTERS

GW151226: Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence

B.P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 31 May 2016)

Binary Black Hole Mergers in the first Advanced LIGO Observing Run

Paper in preparation
https://dcc.ligo.org/LIGO-P1600088/public
Appearing in arXiv soon

Einstein's gravity

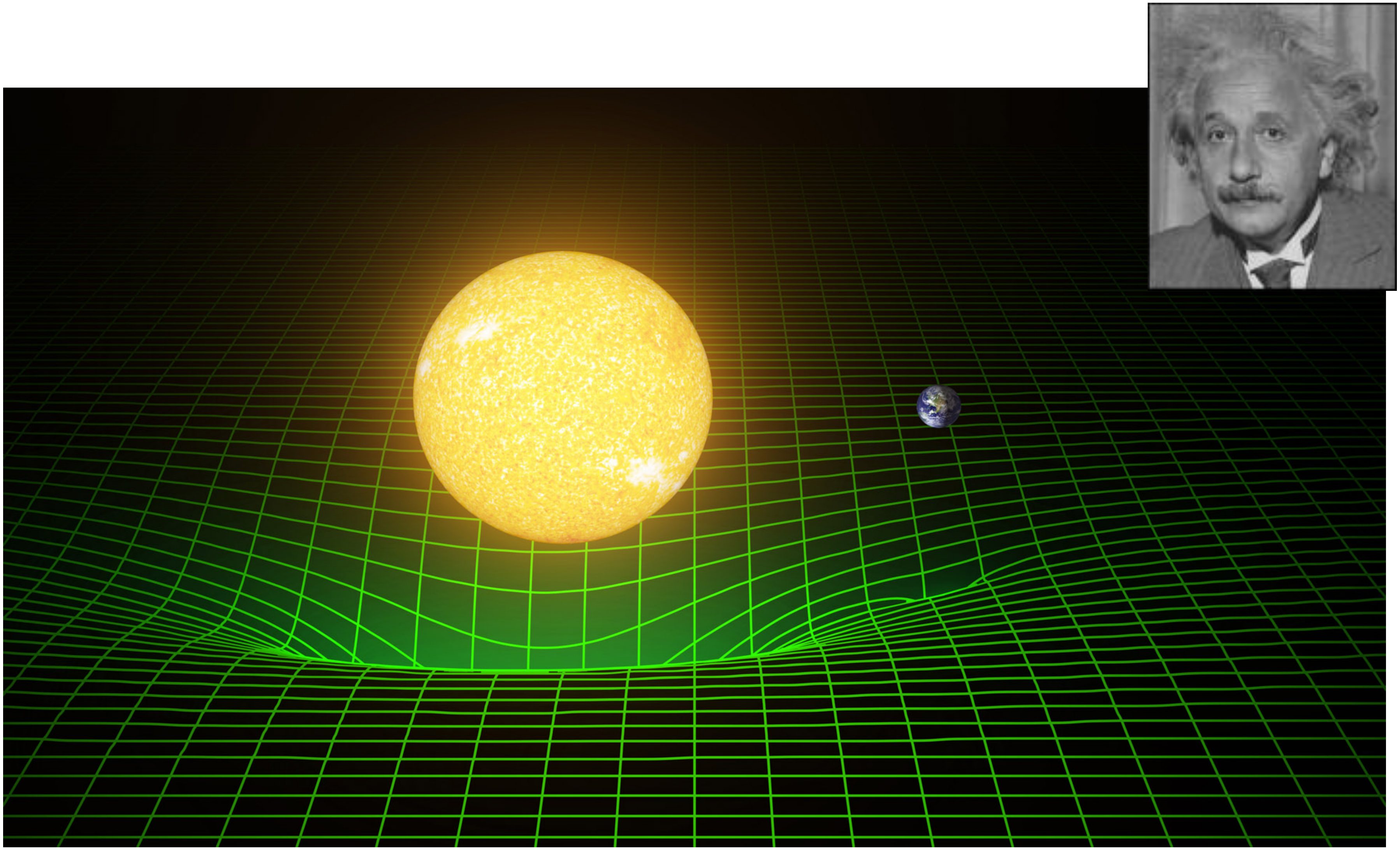
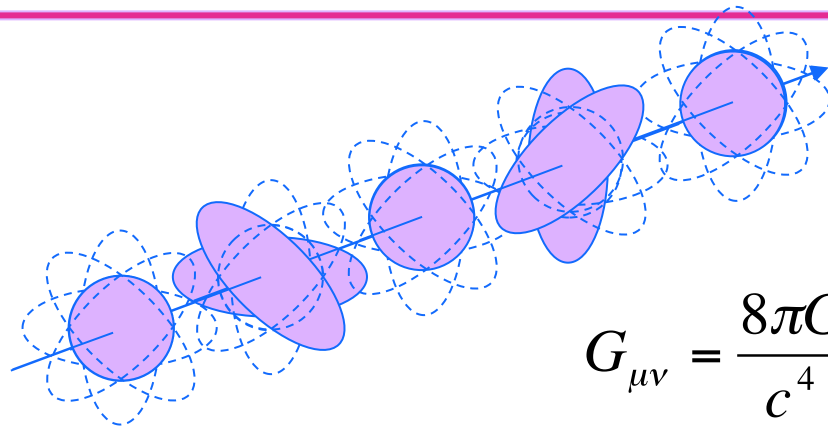


Image Credit: T. Pyle/Caltech/MIT/LIGO Lab

Gravitational waves

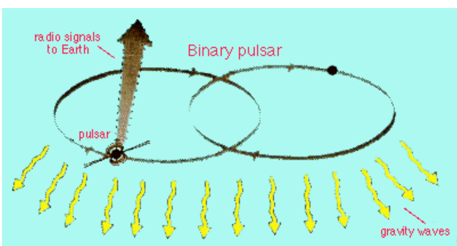


Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

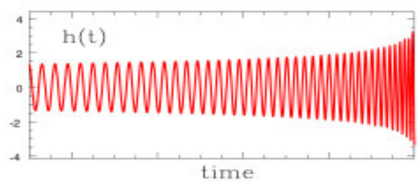
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \, (= 0 \text{ in vacuum})$$

$$h_{\mu\nu} \sim \frac{2G}{c^4 r} \ddot{I}_{\mu\nu}$$

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h = 2\frac{\Delta L}{L}$$

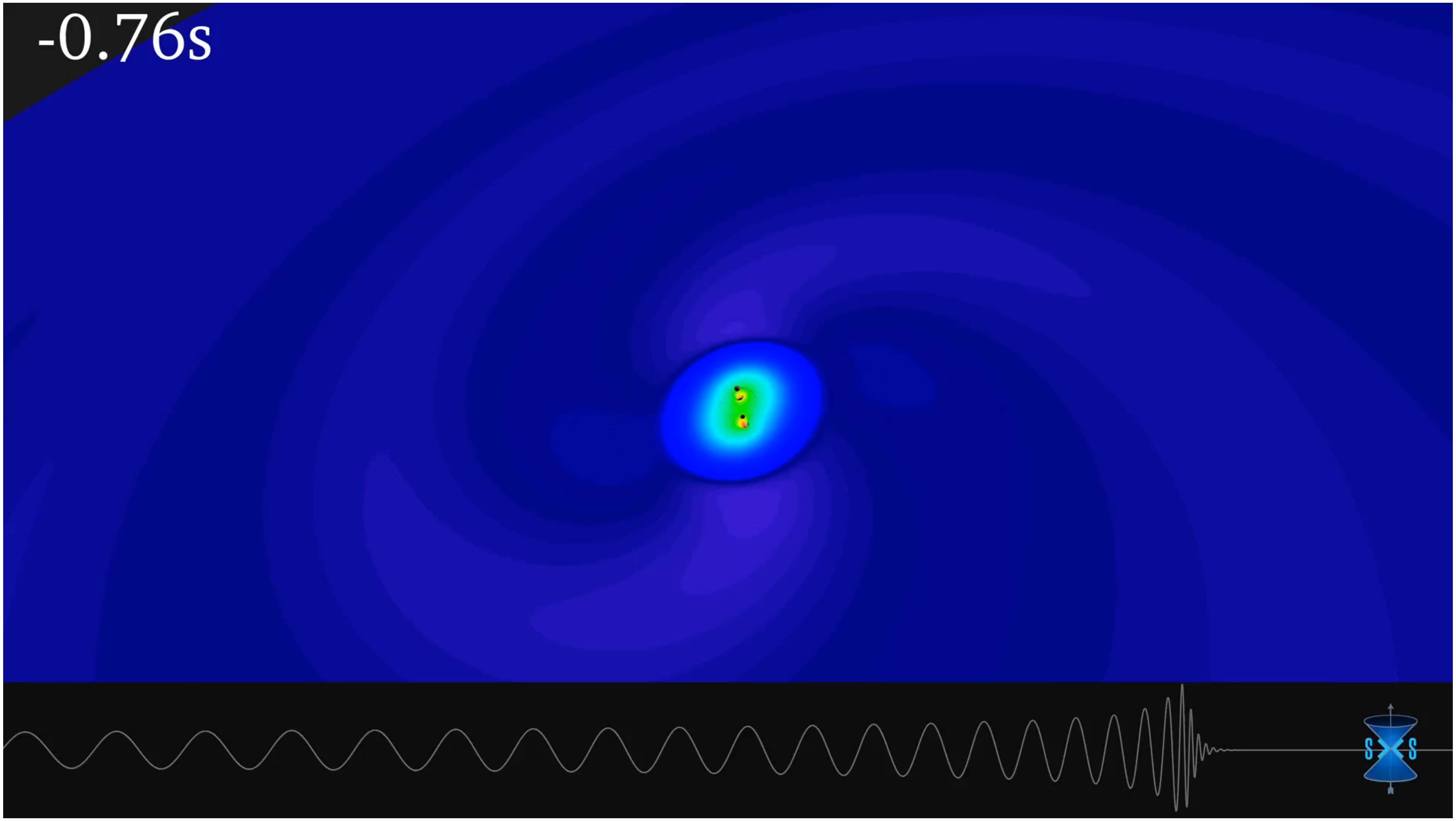


$$h_{\mu\nu} \sim \frac{R_1 R_2}{D r}$$



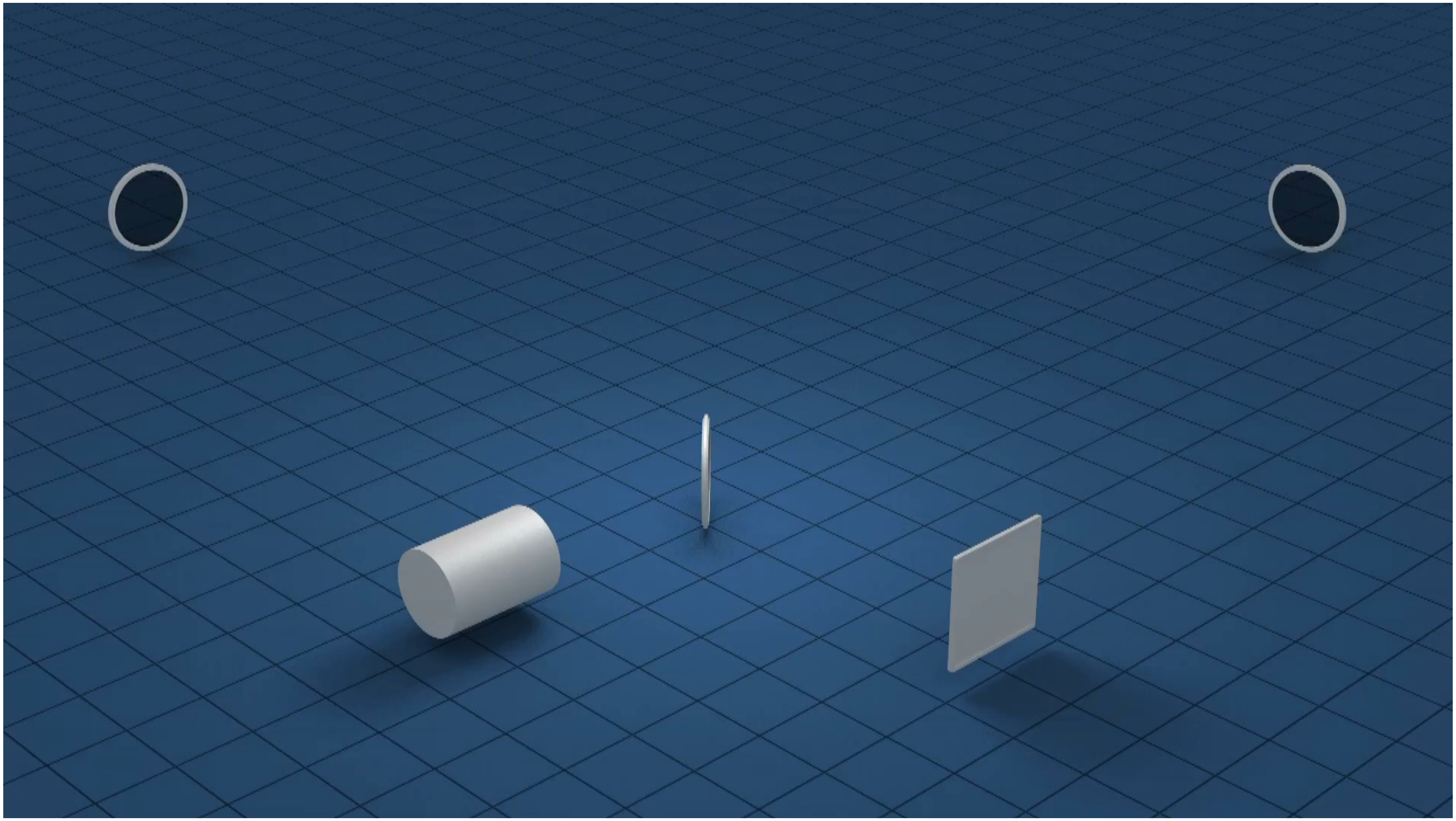
GWs from a NS-NS coalescence in the Virgo cluster has $h \sim 10^{-21}$ near Earth: change the distance between the Sun and the Earth by ~ one atomic diameter, and change 1km distance by $\sim 10^{-18}$ m. They happen ~once every 50 years.

Einstein's gravity



Credit: SXS

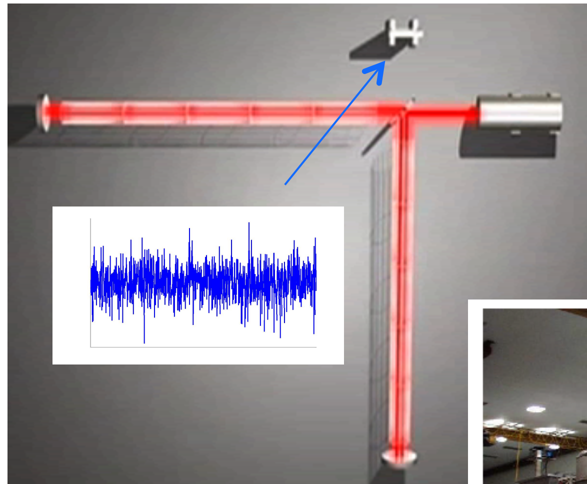
Interferometers

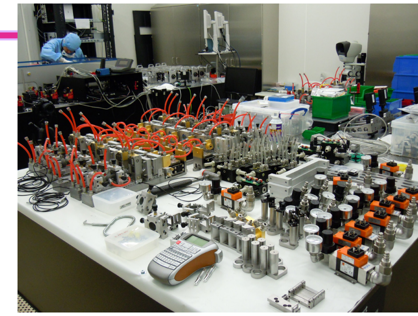


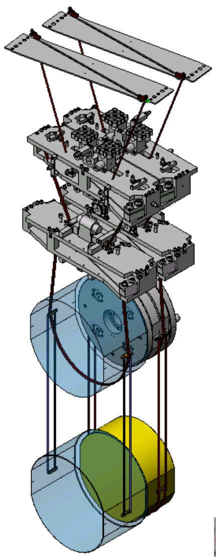
Credit: LIGO/T. Pyle

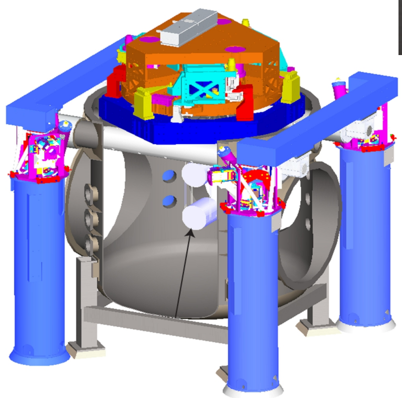
LIGO Detectors

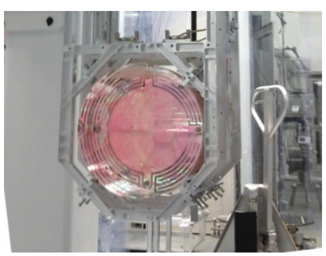
Advanced LIGO detectors

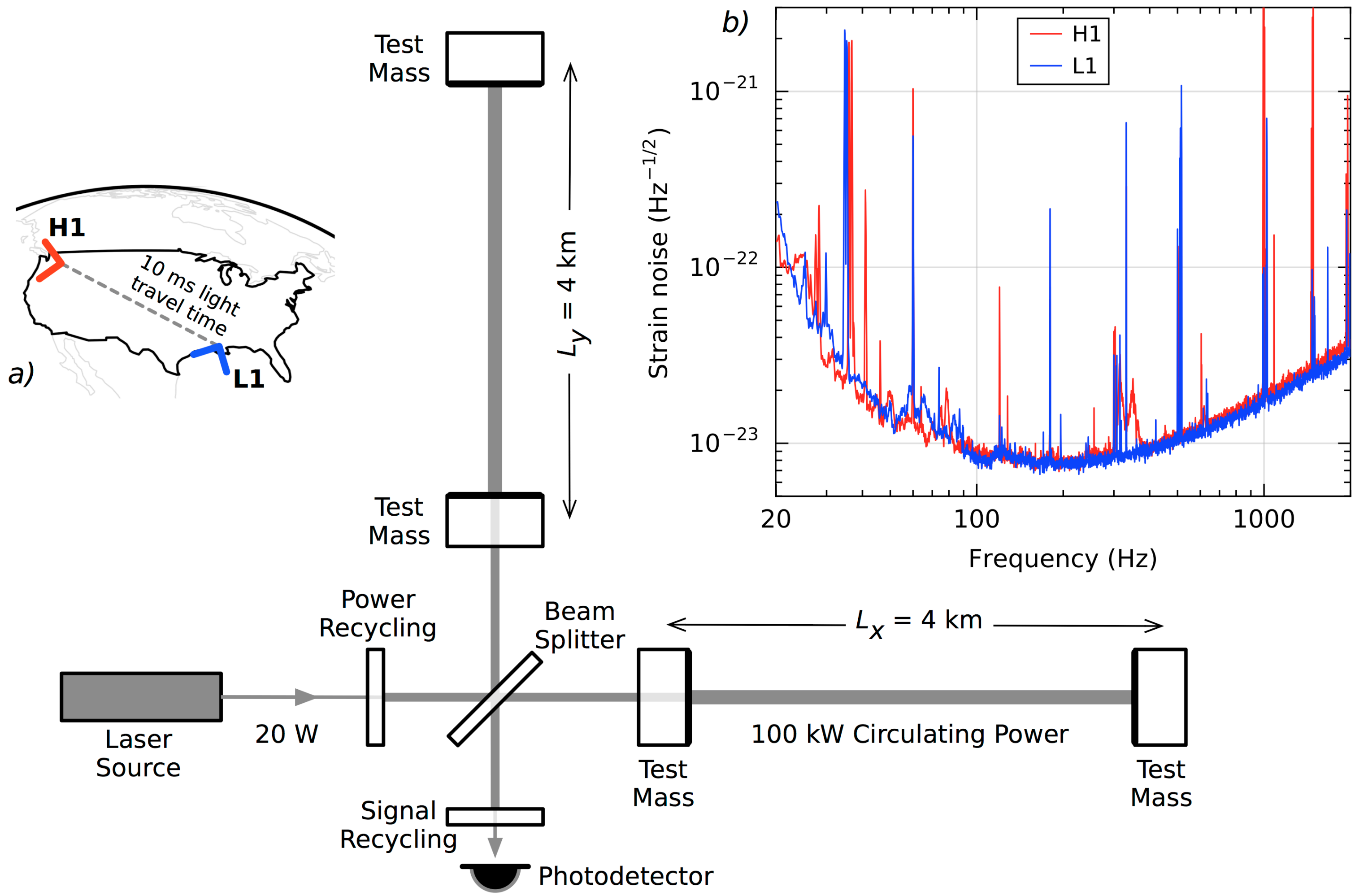


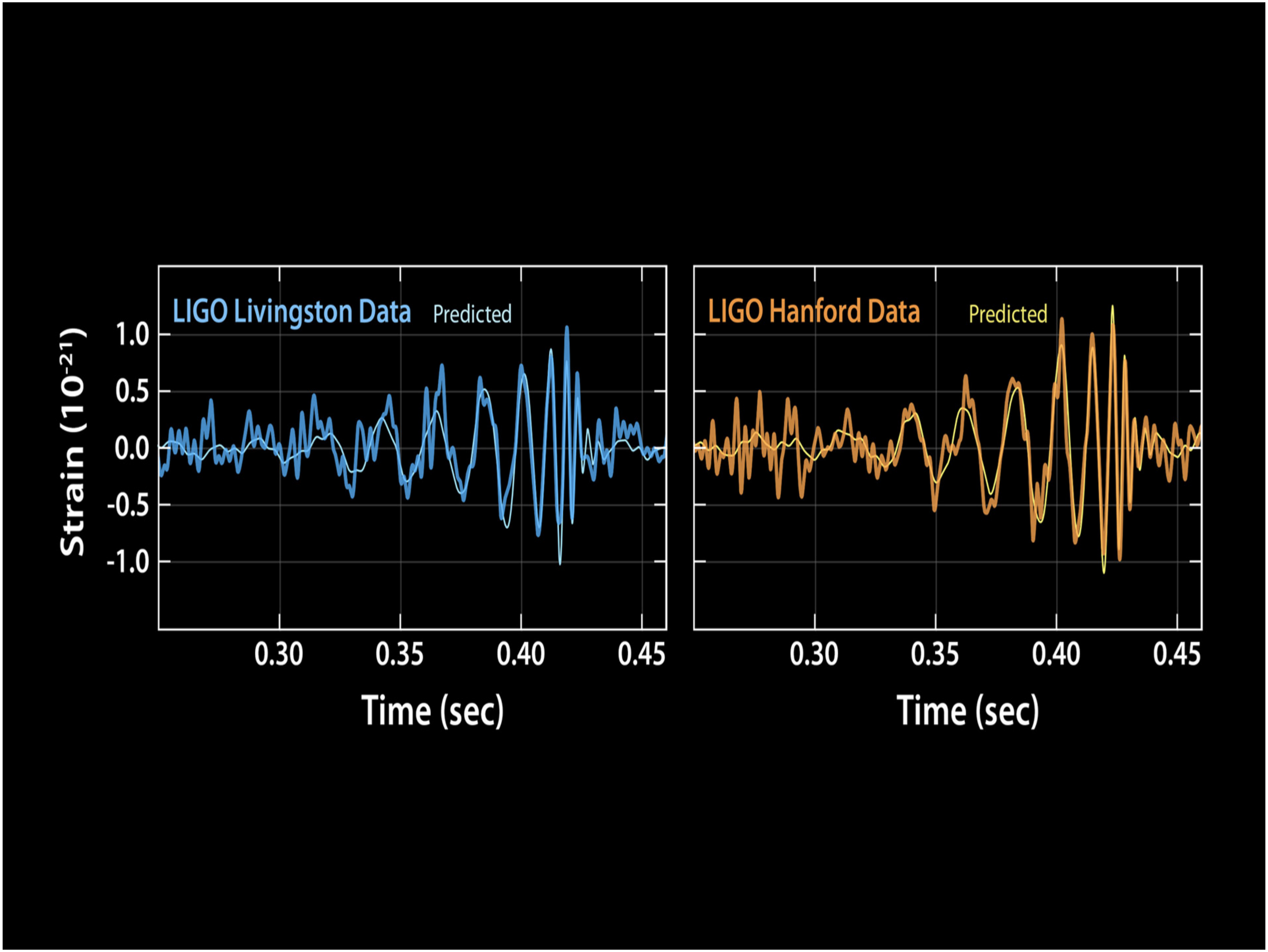


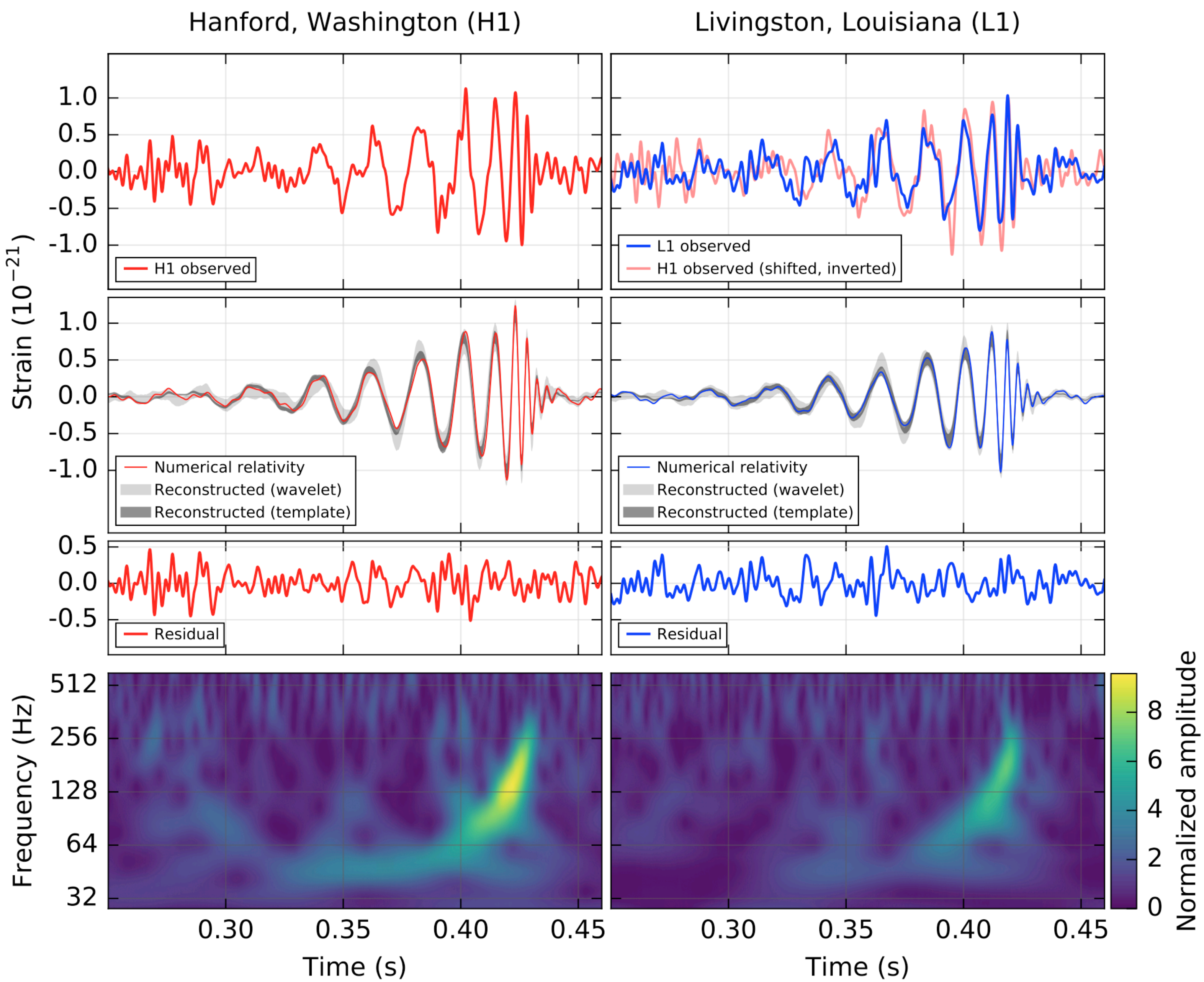






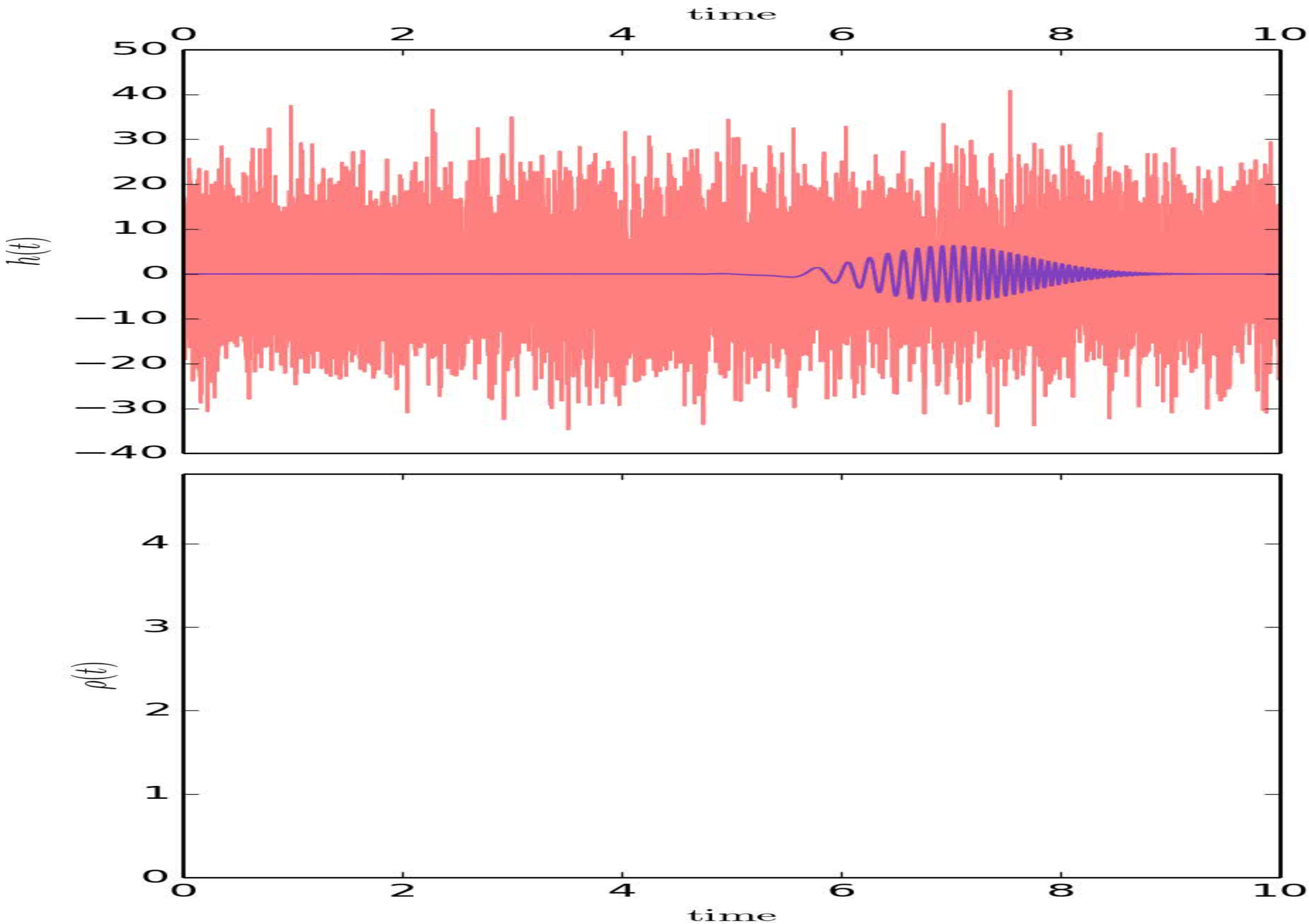

H1
10 ms light travel time
L1
a)
Test Mass
L_y = 4 km
Test Mass
Power Recycling
Beam Splitter
L_x = 4 km
Laser Source
20 W
100 kW Circulating Power
Test Mass
Test Mass
Signal Recycling
Photodetector
b)
H1
L1
Strain noise (Hz$^{-1/2}$)
10^{-21}
10^{-22}
10^{-23}
20
100
1000
Frequency (Hz)

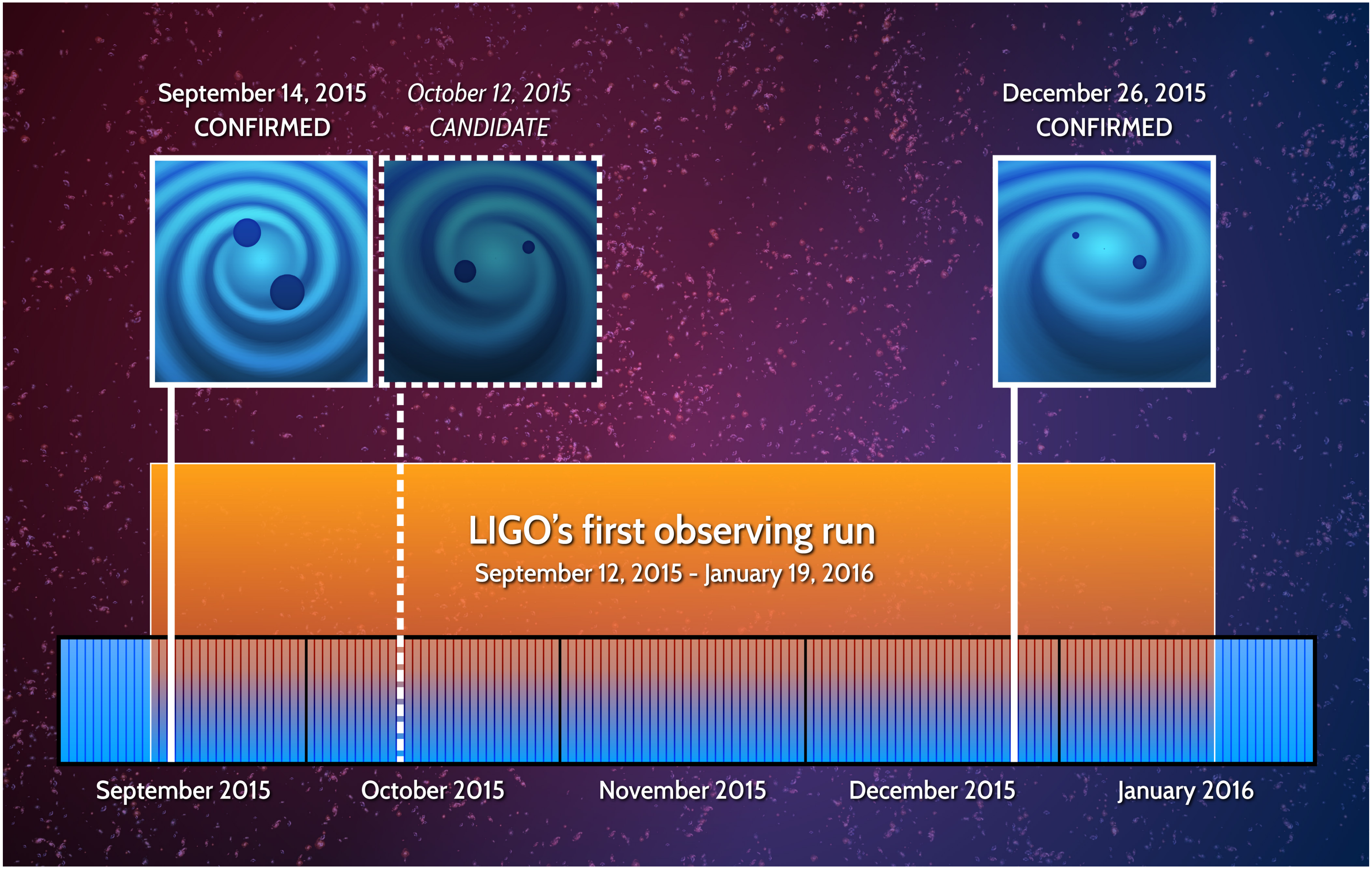

LIGO Livingston Data
Predicted
LIGO Hanford Data
Predicted
Strain (10-21)
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)
Time (sec)



Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain (10^{-21})
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
Time (s)
Normalized amplitude

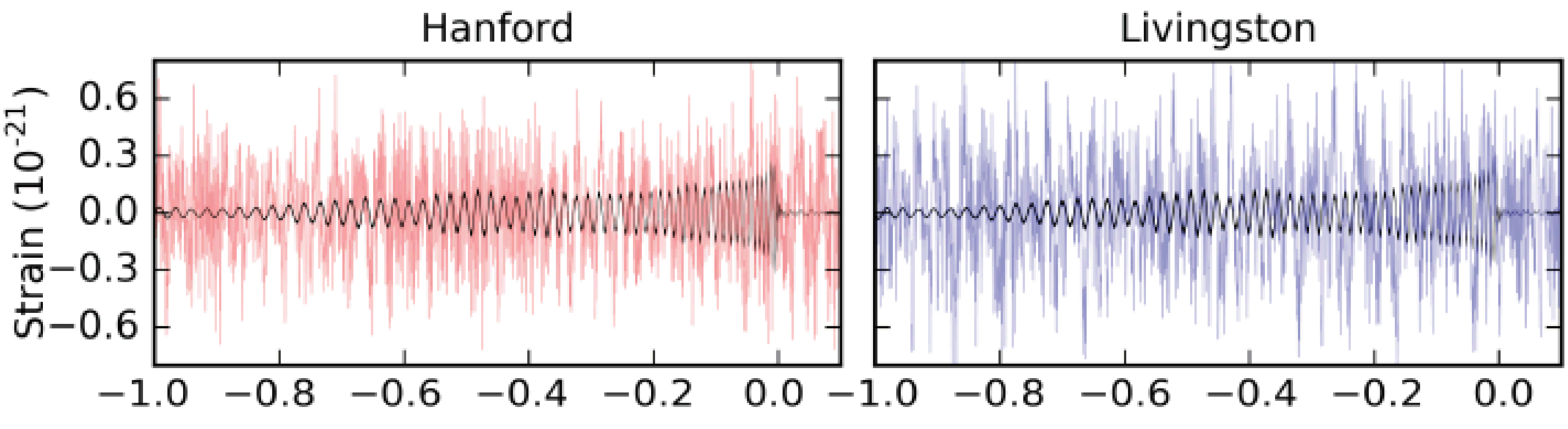
Searching for a specific waveform



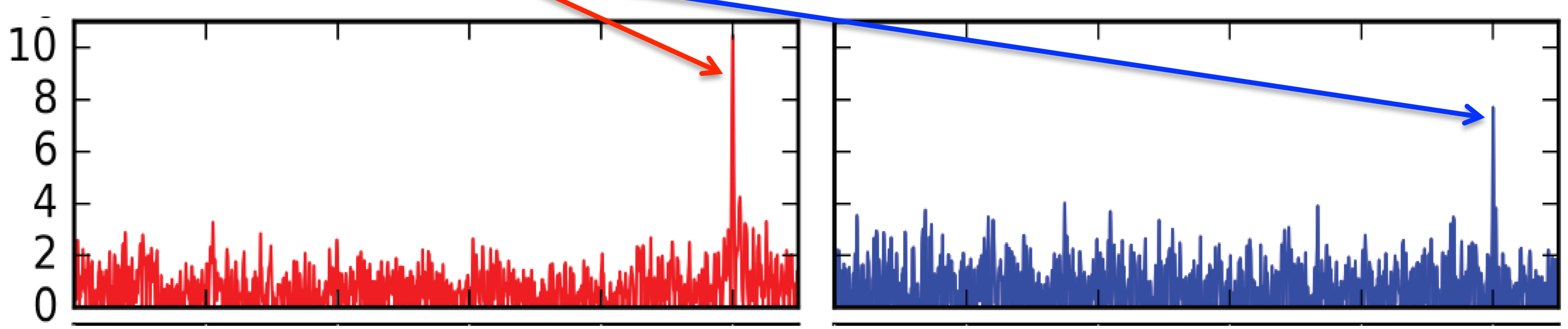


LIGO-G1601317

Filtered detector output and filtered best matching waveform

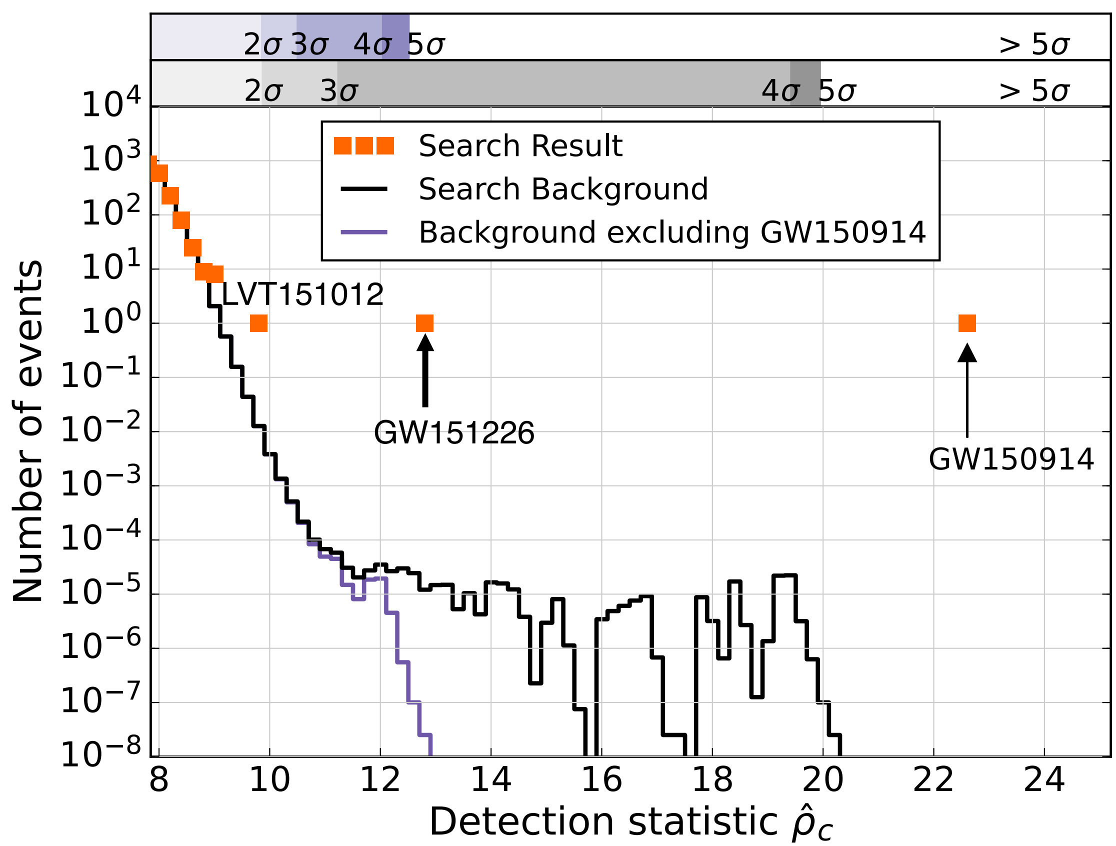


Signal-to-noise (SNR) when best template matches at coalescence time

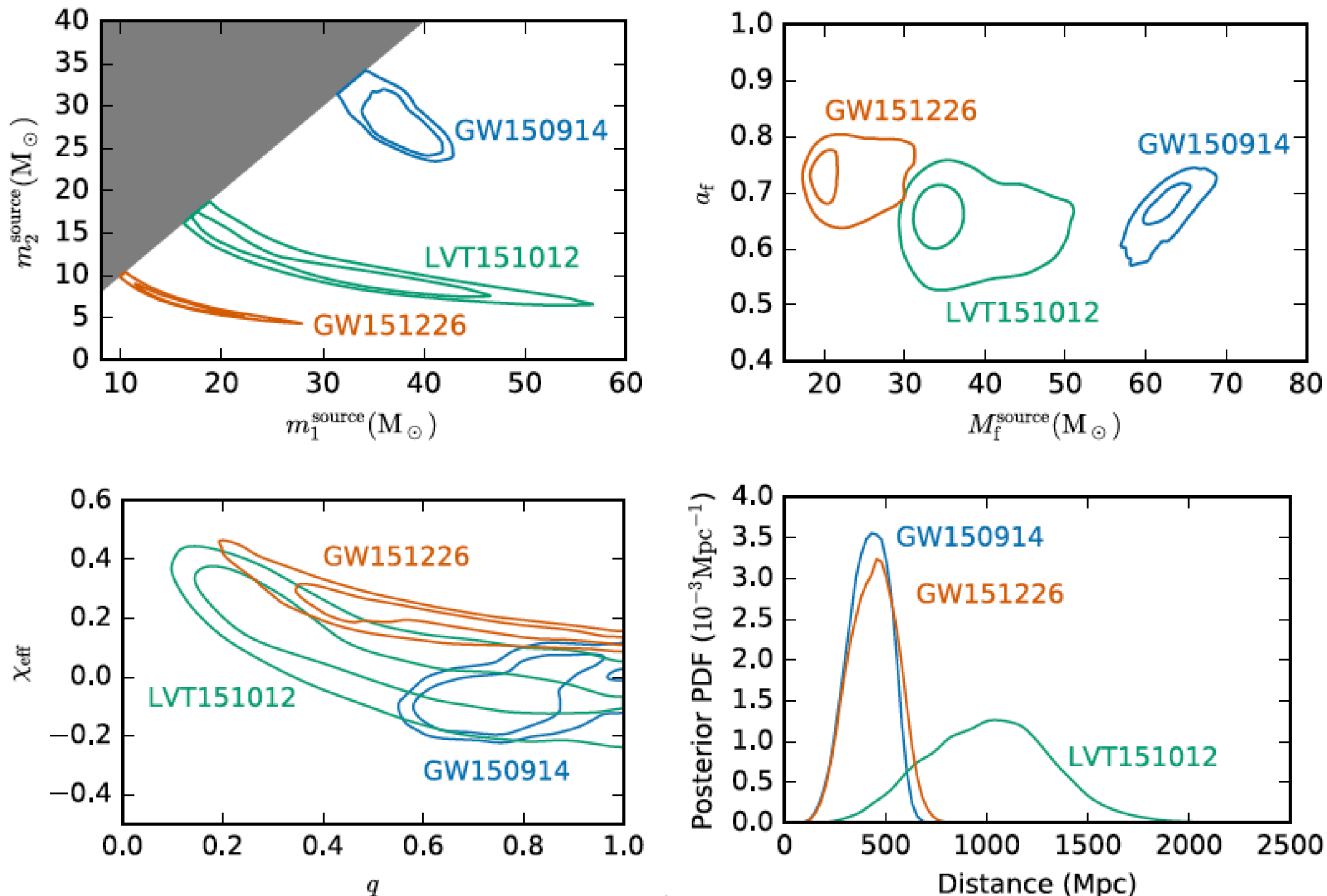


O1 BBH search

Search for binary black holes systems with black holes larger than 2 $M_\odot$ and total mass less than100 $M_\odot$, in O1 (Sep 12, 2015-Jan 19, 2016, ~48 days of coincident data)

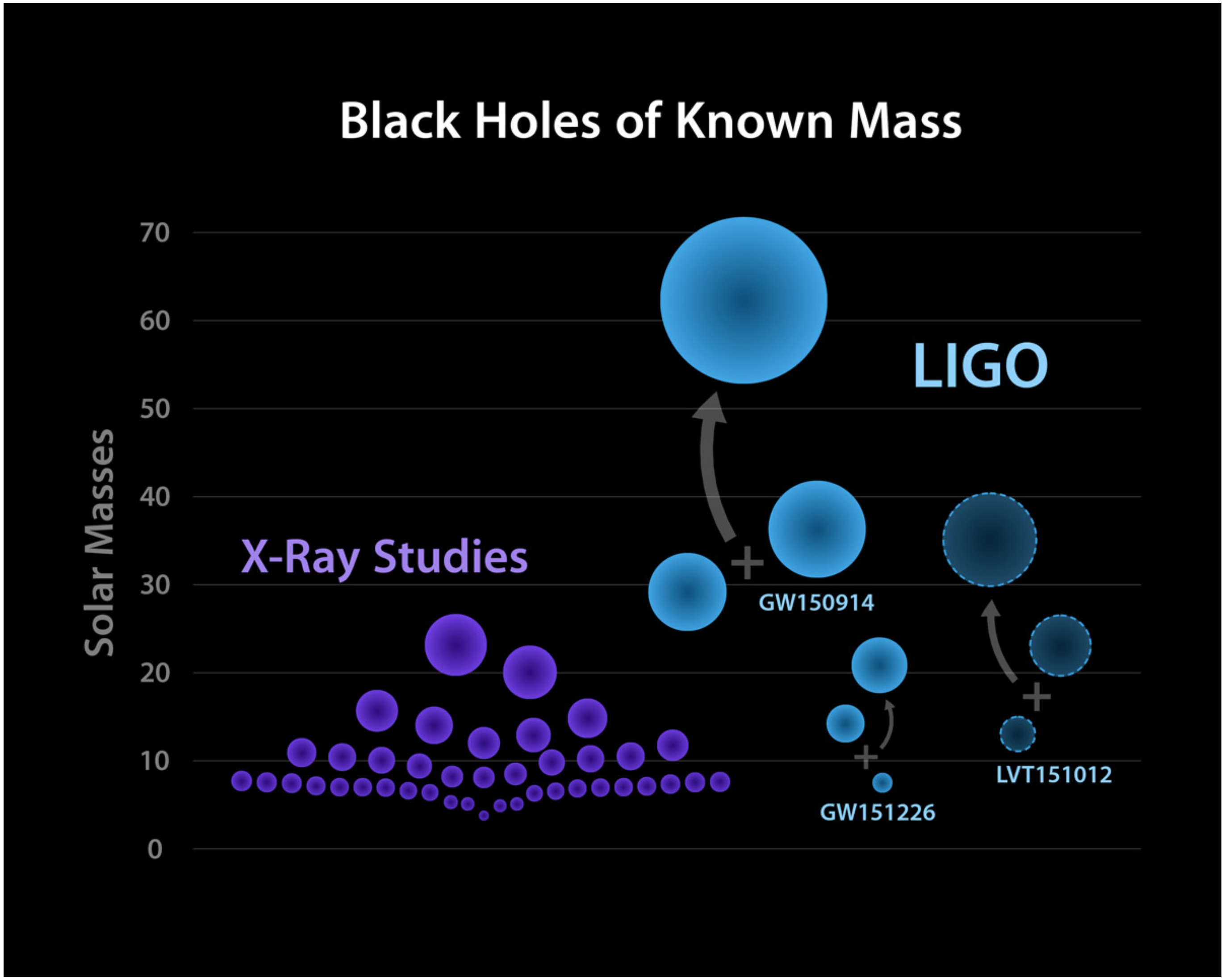


Parameters of the BBH systems

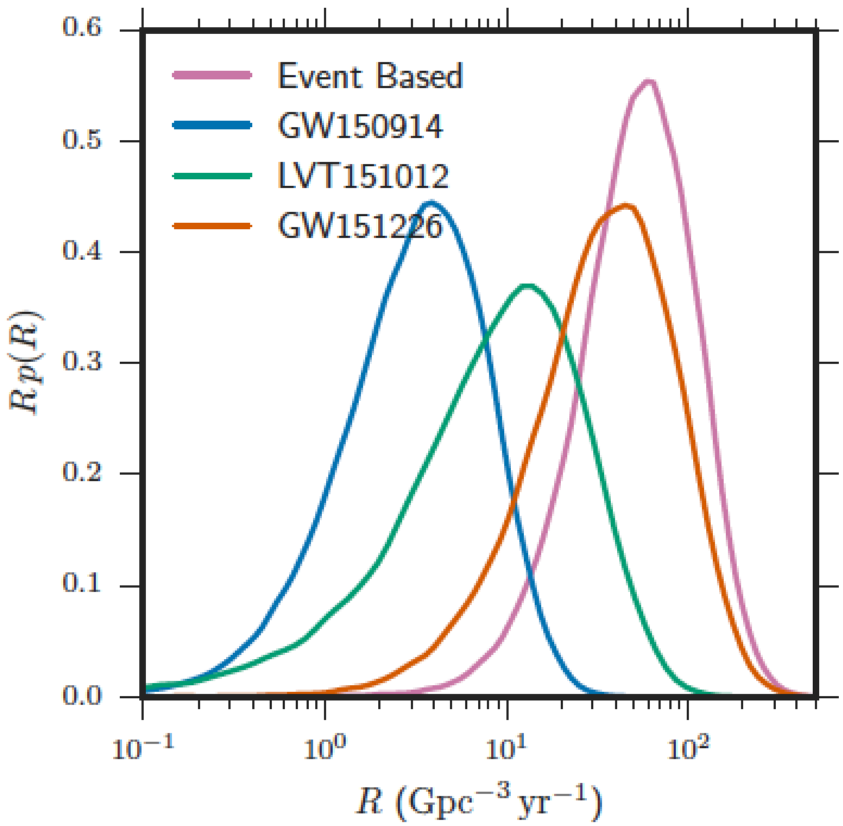


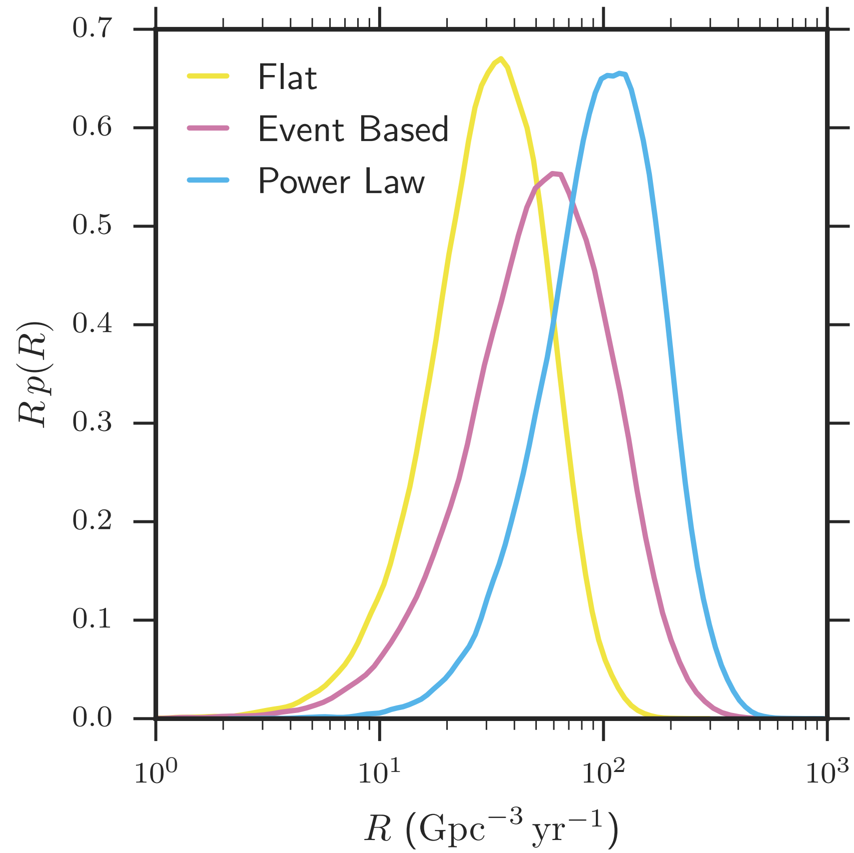
50% and 90% credible regions

Filling in the black hole catalog



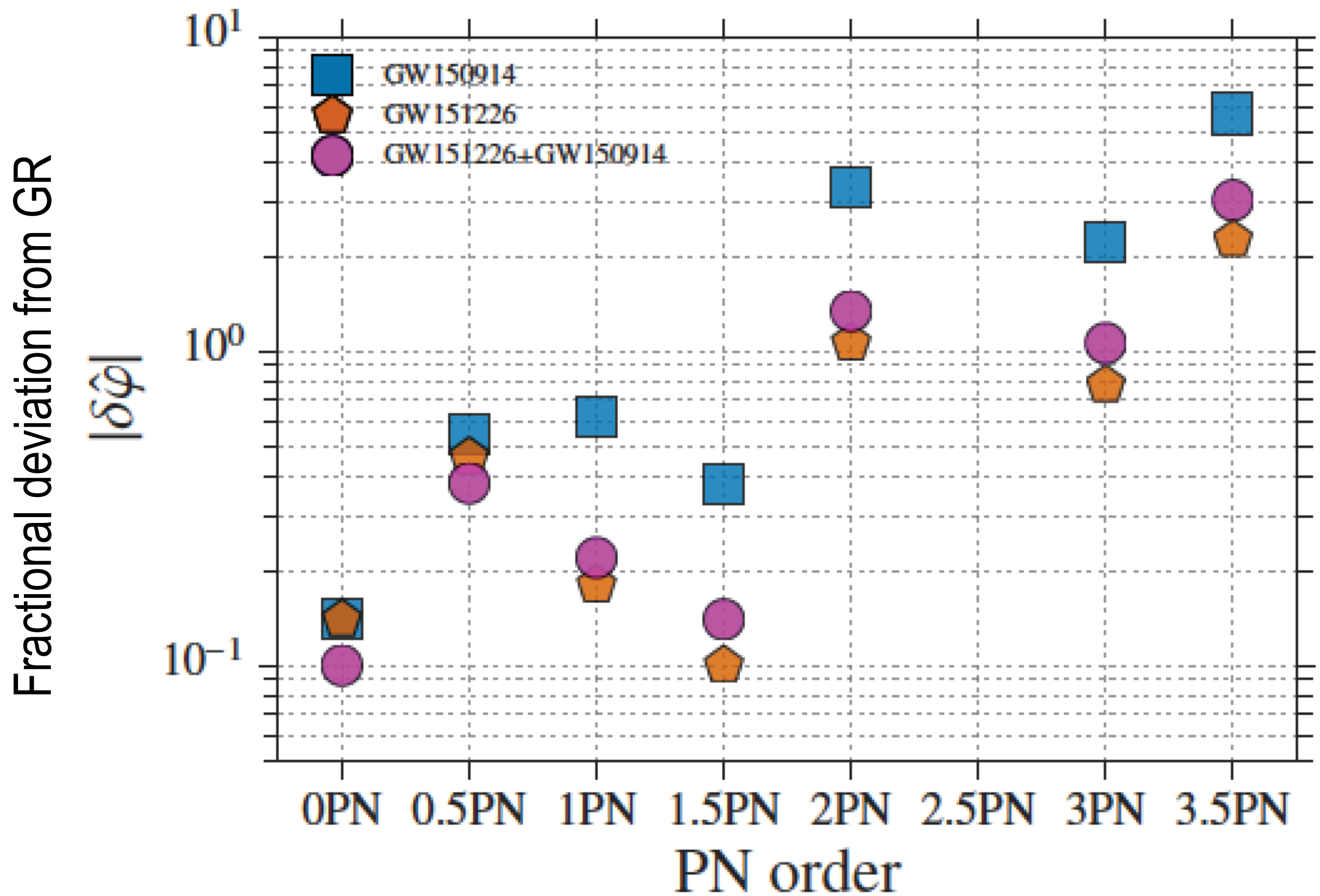
BBH merger rate





90% allowed range: [9-240] /Gpc^3/yr

Testing General Relativity



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

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

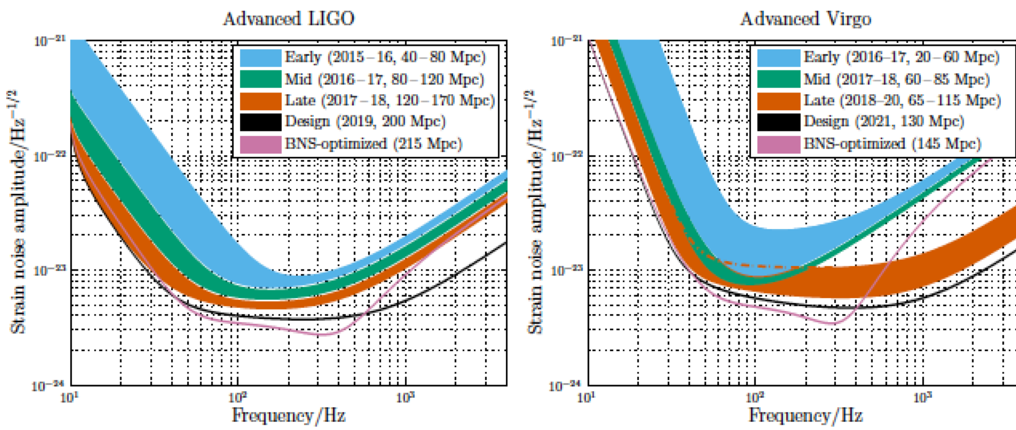


Figure 1: aLIGO (*left*) and AdV (*right*) target strain sensitivity as a function of frequency. The binary neutron-star (BNS) range, the average distance to which these signals could be detected, is given in megaparsec. Current notions of the progression of sensitivity are given for early, mid and late commissioning phases, as well as the final design sensitivity target and the BNS-optimized sensitivity. While both dates and sensitivity curves are subject to change, the overall progression represents our best current estimates.

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).

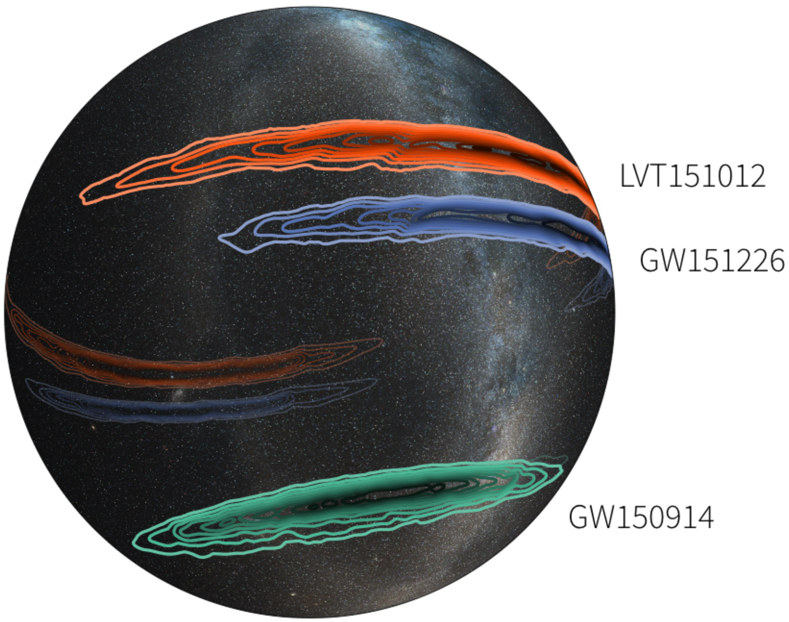
2016 – 2017 (O2) A six-month run with H1L1 at 80 – 120 Mpc and V1 at 20 – 60 Mpc.

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

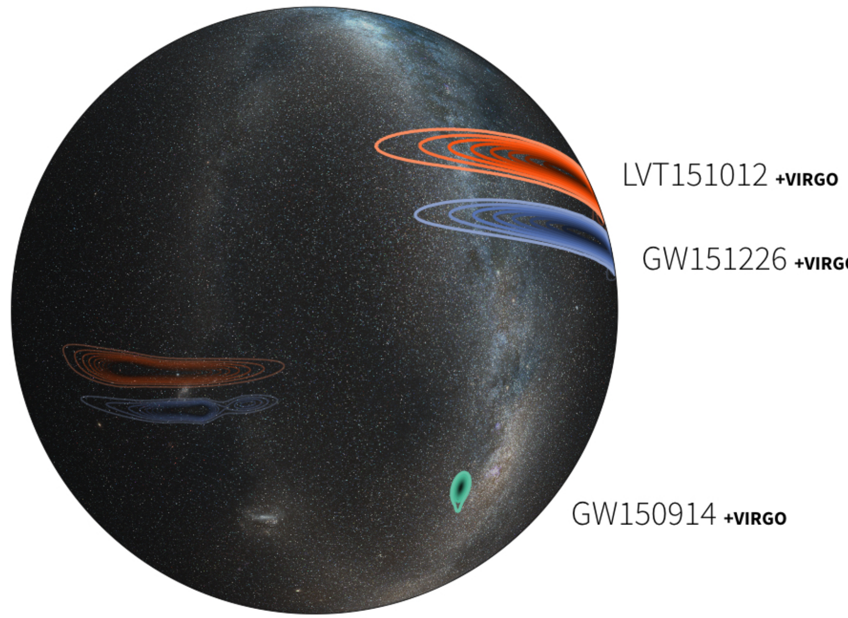
2019+ Three-detector network with H1L1 at full sensitivity of 200 Mpc and V1 at 65 – 115 Mpc.

Sky localization: more detectors needed!

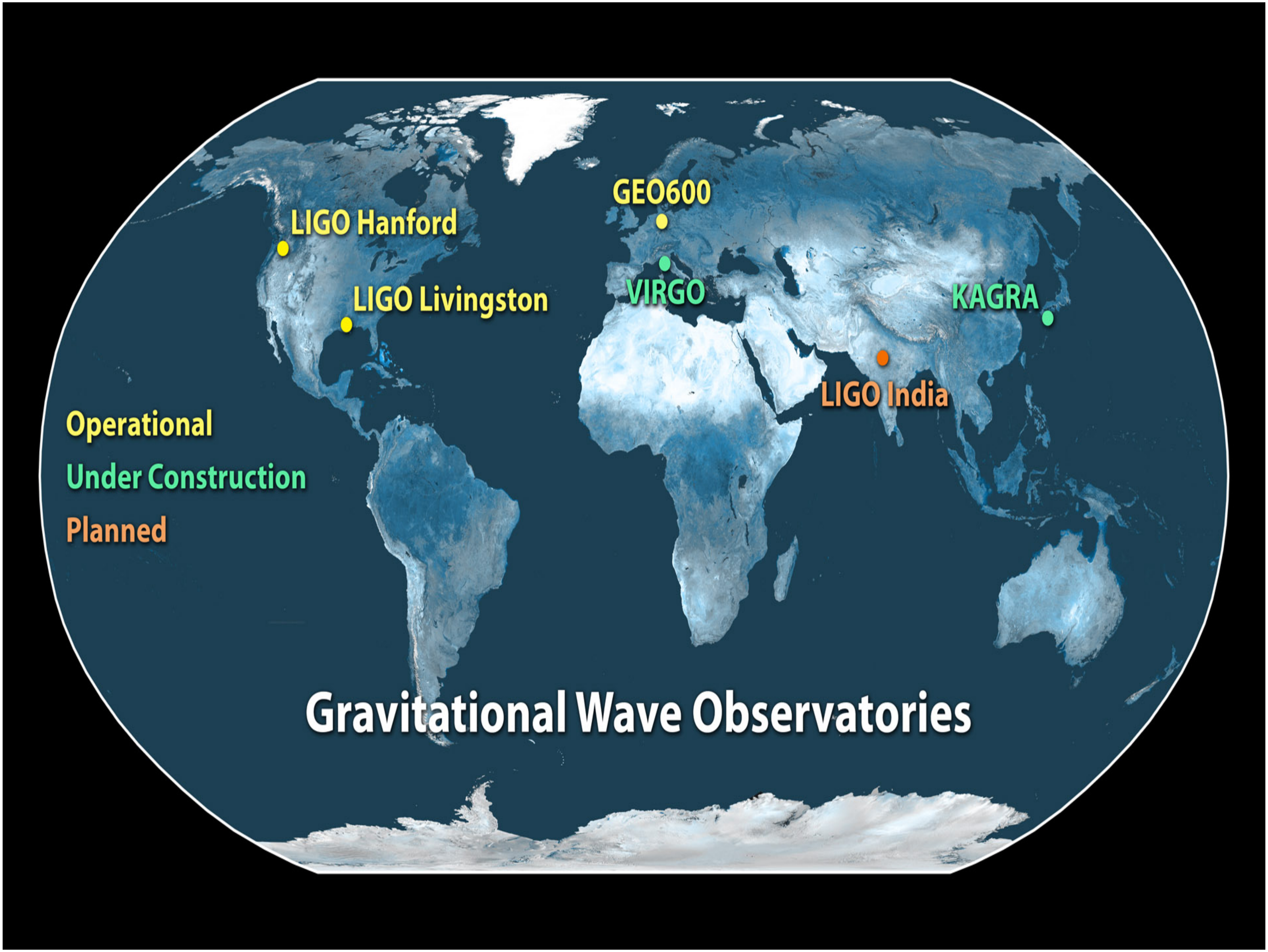
Actual estimates

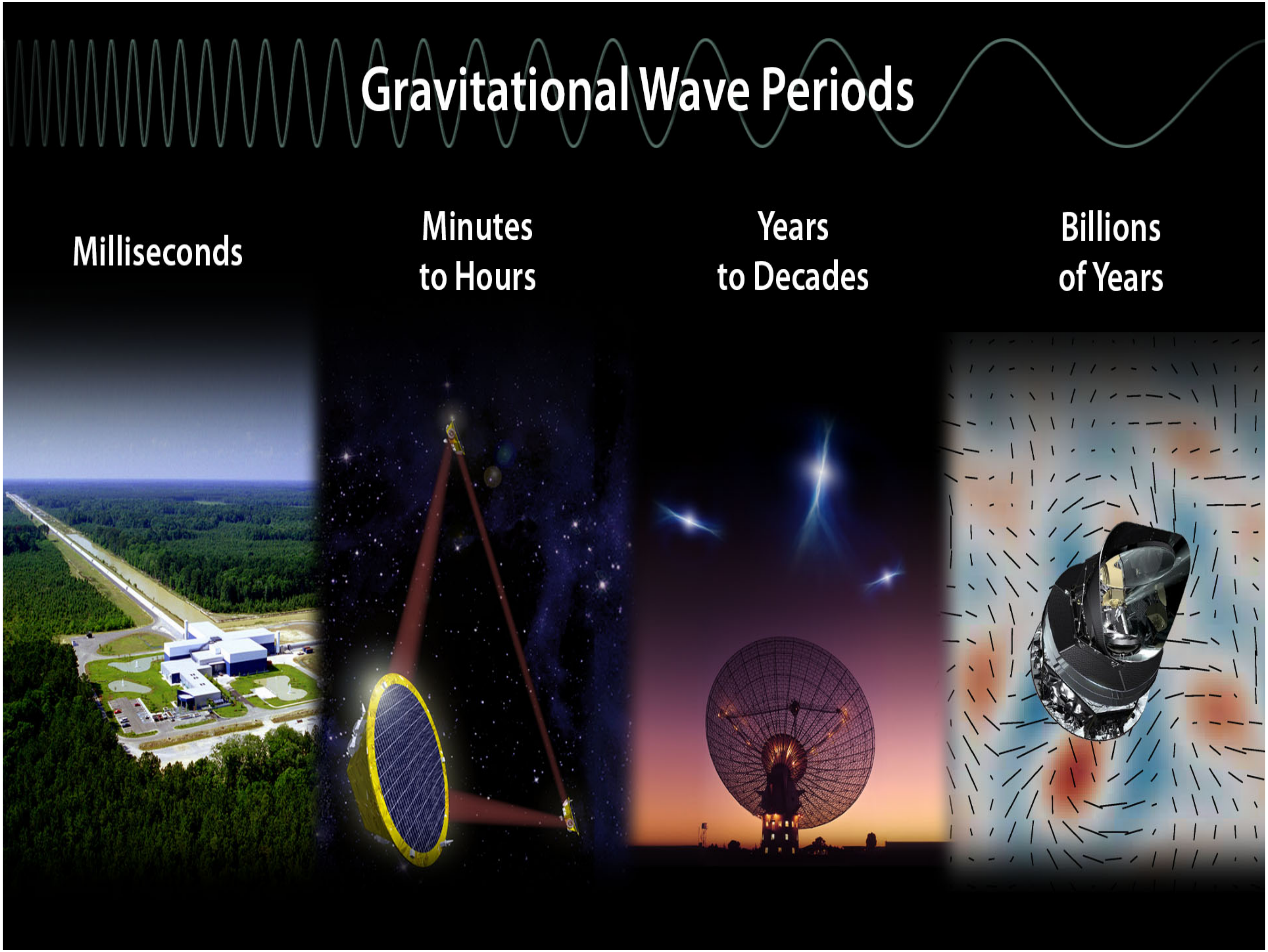


Simulated estimates with Virgo

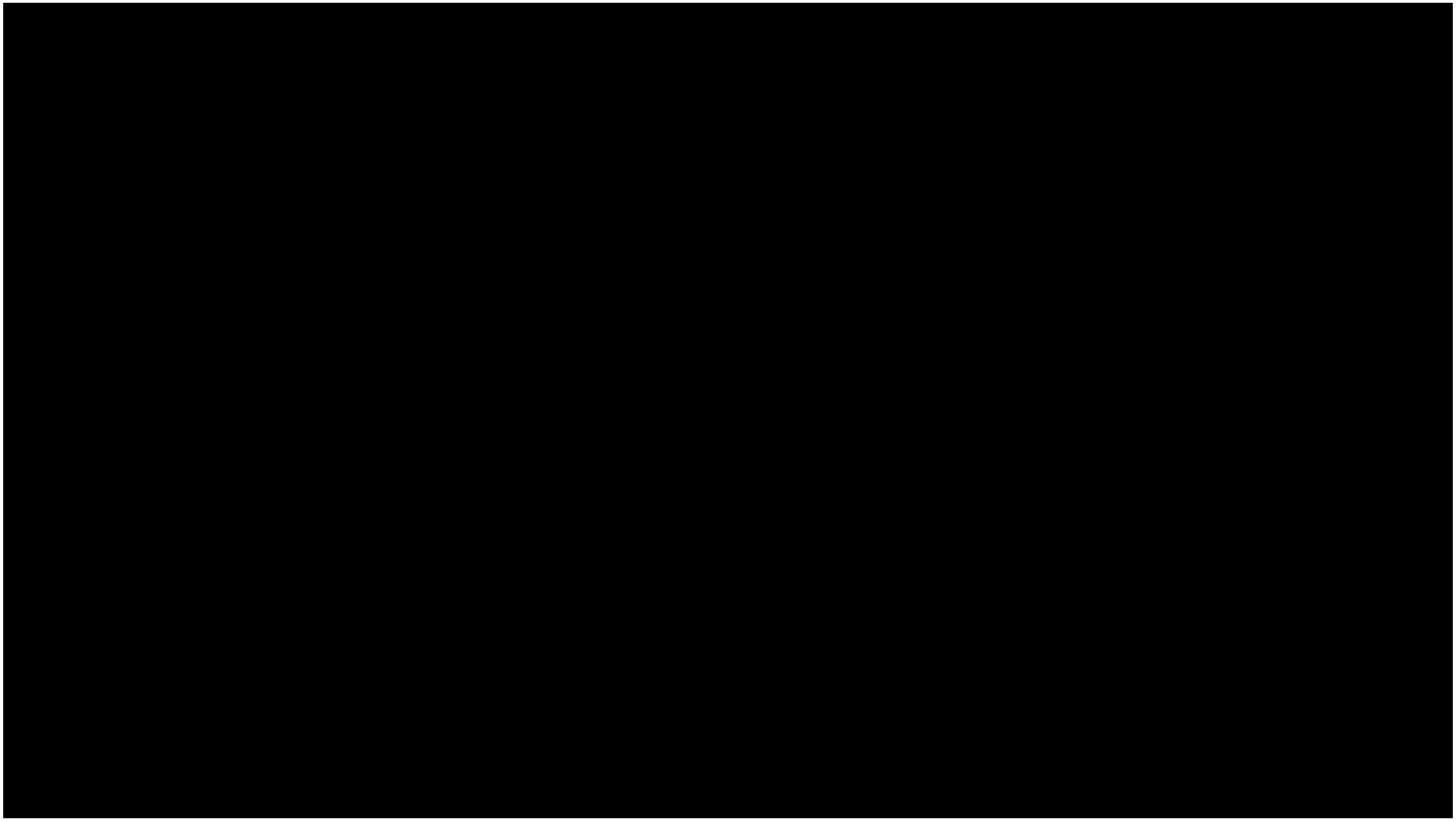


3-D projection of the Milky Way onto a transparent globe shows the probable locations of confirmed detections GW150914 (green), and GW151226 (blue), and the candidate LVT151012 (red). The outer contour for each represents the 90 percent confidence region while the innermost contour is the 10 percent region.
Image credit: LIGO/Axel Mellinger


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


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

Gravity's music



Thanks!