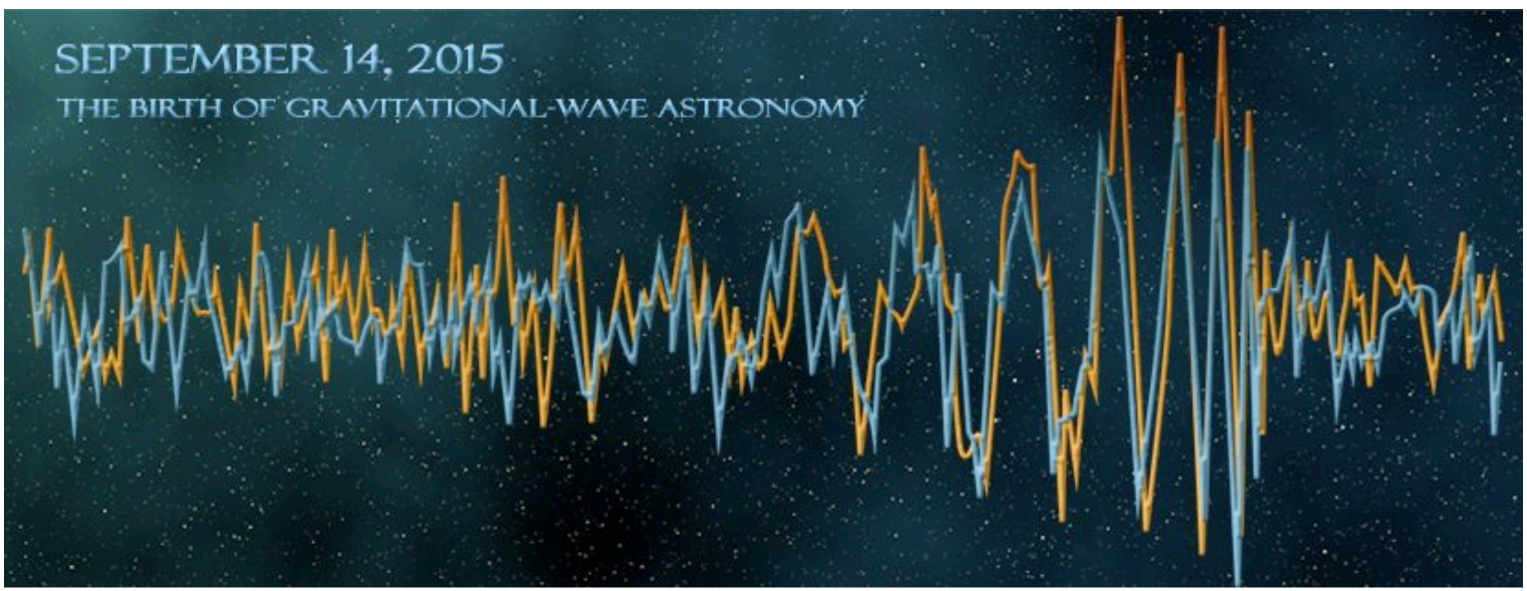
Detection of gravitational waves

Gabriela González
Louisiana State University

For the LIGO Scientific Collaboration and
the Virgo Collaboration

National Academy of Sciences Annual Meeting

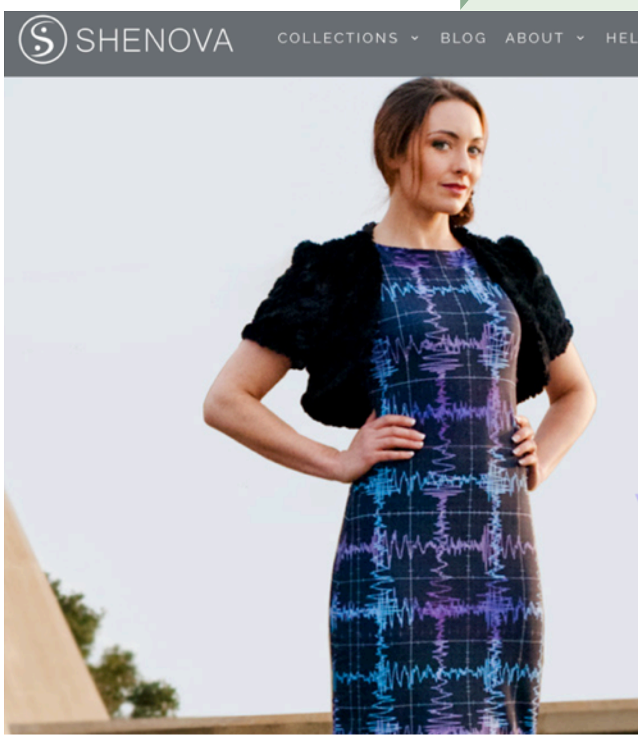
May 1, 2016

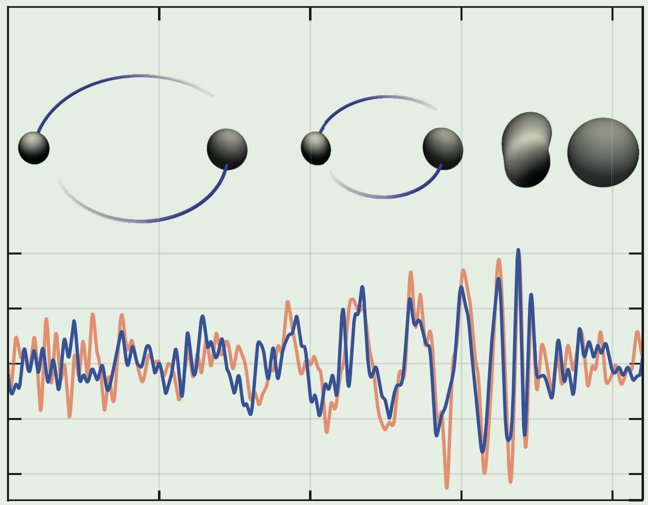


PRL 116, 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

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

https://papers.ligo.org/

- Use LIGO Data
- LIGO's Impact on Science
- LIGO R&D
- Publications
- Collaborate
- Detection Papers

Detection Papers

Discovery Paper

"Observation of Gravitational Waves from a Binary Black Hole Merger"
Published in *PRL* **116**, 061102 (2016).

Related papers

"Observing gravitational-wave transient GW150914 with minimal assumptions"

"GW150914: First results from the search for binary black hole coalescence with Advanced LIGO4"

"Properties of the binary black hole merger GW150914"

"The Rate of Binary Black Hole Mergers Inferred from Advanced LIGO Observations Surrounding GW150914"

"Astrophysical Implications of the Binary Black-Hole Merger GW150914"

"Tests of general relativity with GW150914"

"GW150914: Implications for the stochastic gravitational-wave background from binary black holes"

"Calibration of the Advanced LIGO detectors for the discovery of the binary black-hole merger GW150914"

"Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914"

"High-energy Neutrino follow-up search of Gravitational Wave Event GW150914 with IceCube and ANTARES"

"GW150914: The Advanced LIGO Detectors in the Era of First Discoveries"

"Localization and broadband follow-up of the gravitational-wave transient GW150914"

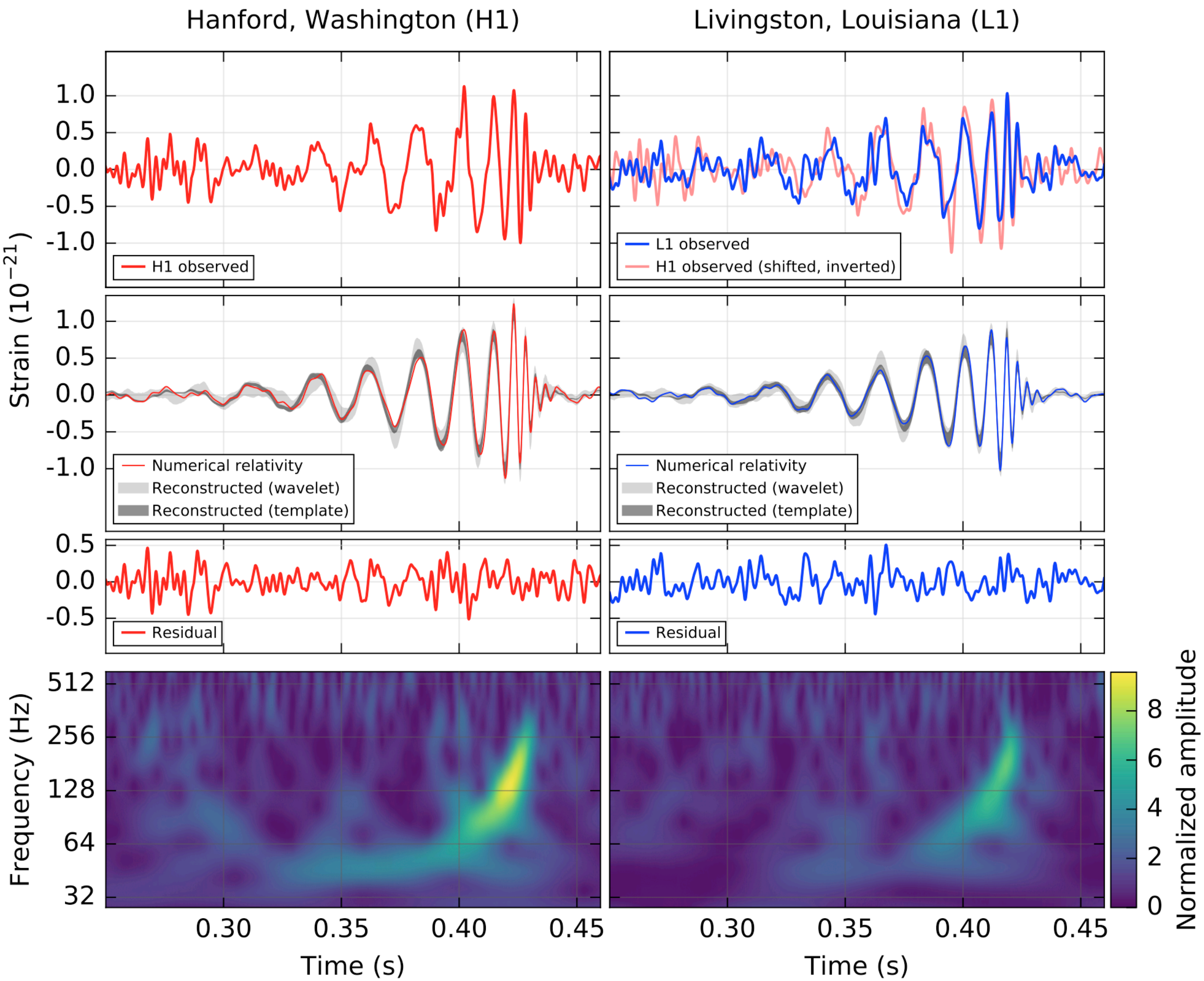
GW150914 Data Release

Data release at **LIGO Open Science Center** (LOSC) website.

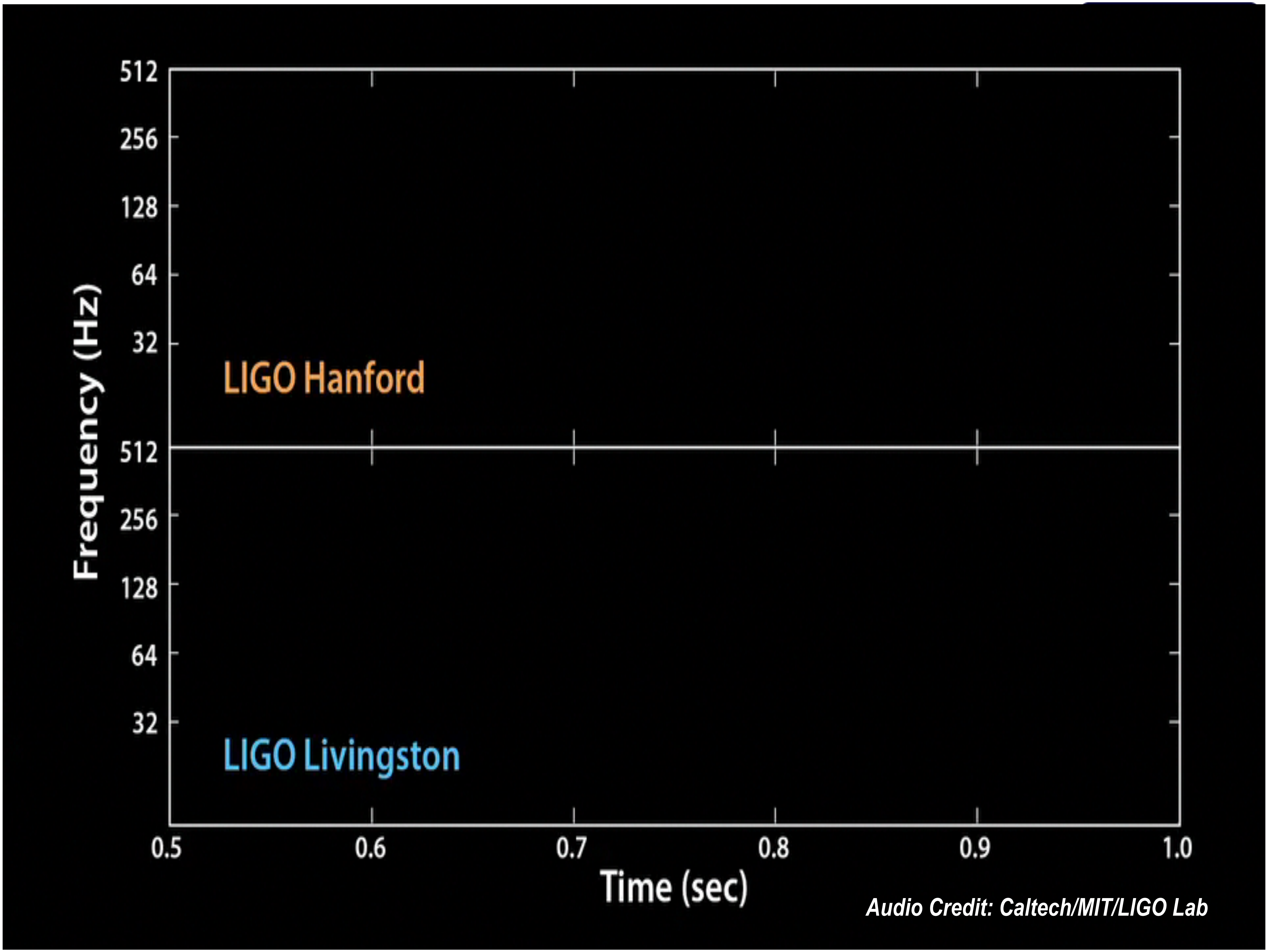
LIGO Scientific Collaboration

LSC

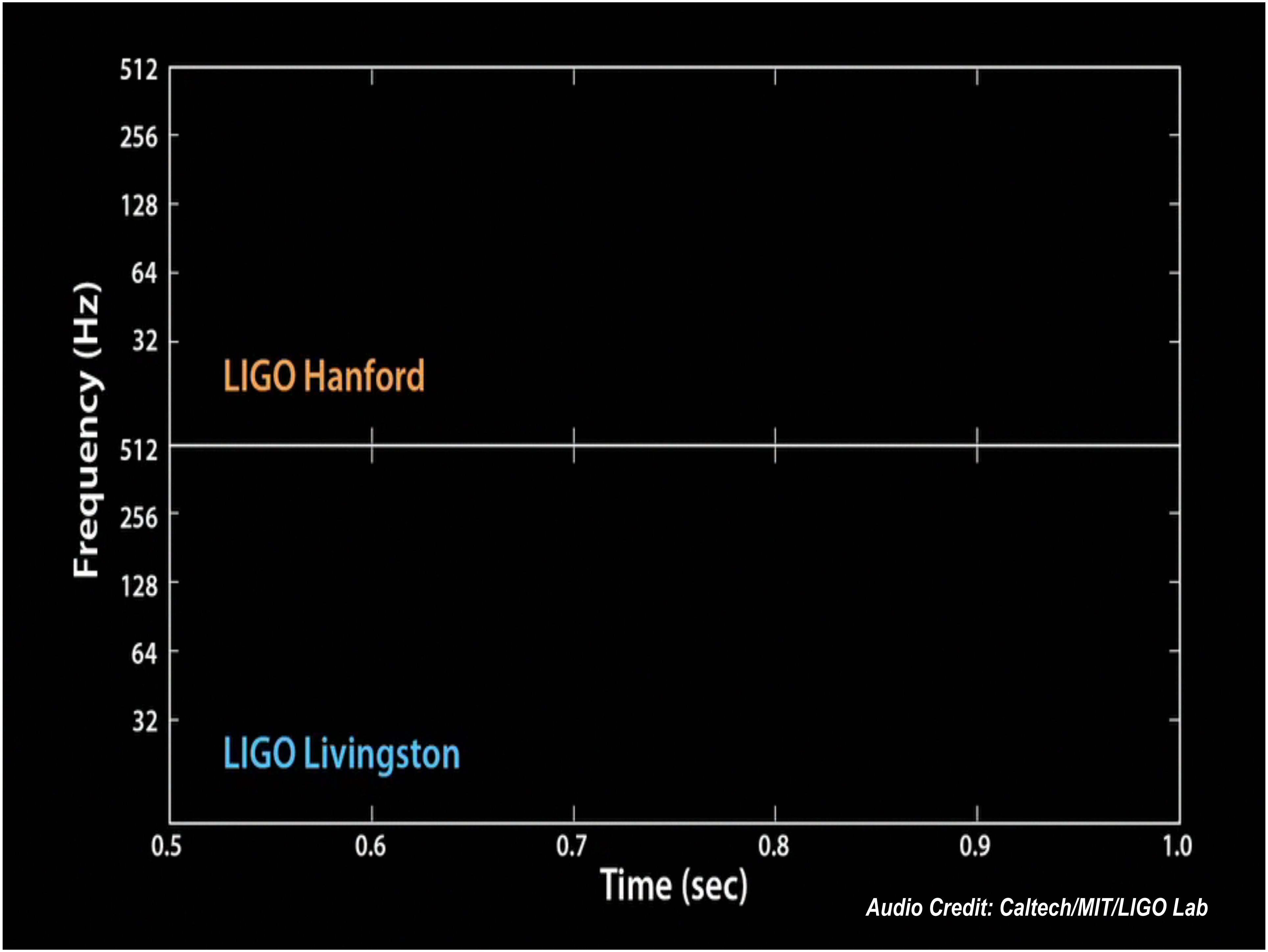
Trinity University
University of Maryland
Andrews University
Washington State University
California State University Fullerton
The University of Alabama in Huntsville
Whitman College
American University Washington, DC
Sonoma State University
indigo
Montclair State University
University of Glasgow
Australian National University
University of the West of Scotland UWS
Texas Tech University
Tsinghua University
R·I·T
Max Planck Institute for Gravitational Physics Albert Einstein Institute
University of Strathclyde
Michigan
CITA | ICAT Canadian Institute for Theoretical Astrophysics L'institut Canadien d'astrophysique théorique
Università degli Studi del Sannio
Goddard Space Flight Center
ICTP SAIFR
The University of Western Australia
University of Cambridge
Southern University Agricultural & Mechanical College
Columbia University in the City of New York
The University of Chicago
Montana State University
The University of Mississippi
The University of Adelaide Australia
Caltech
University of Minnesota
University of Birmingham
The University of Melbourne
Universitat de les Illes Balears
University of Washington
UTRGV
University of Wisconsin Milwaukee
Syracuse University
Cardiff University Prifysgol Caerdydd
Northwestern
Monash University
University of Florida
Georgia Institute of Technology
Korean Gravitational-Wave Group
LSU Louisiana State University
ACIGA
University of Southampton
Charles Sturt University
Embry-Riddle Aeronautical University
Leibniz Universität Hannover
PennState
Science & Technology Facilities Council Rutherford Appleton Laboratory



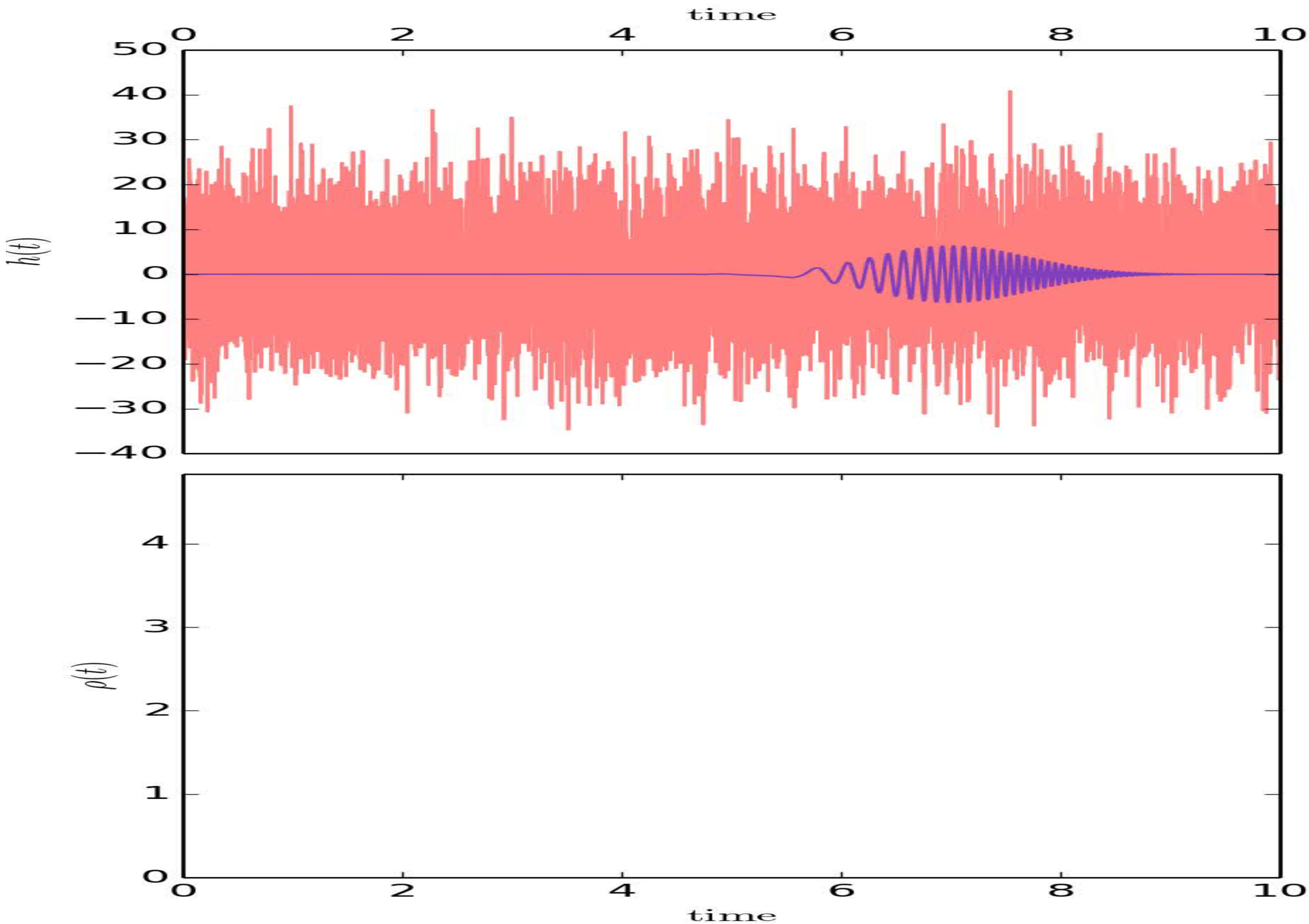
PRL 116, 061102 (2016)



Frequency (Hz)
512
256
128
64
32
LIGO Hanford
512
256
128
64
32
LIGO Livingston
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)
Audio Credit: Caltech/MIT/LIGO Lab

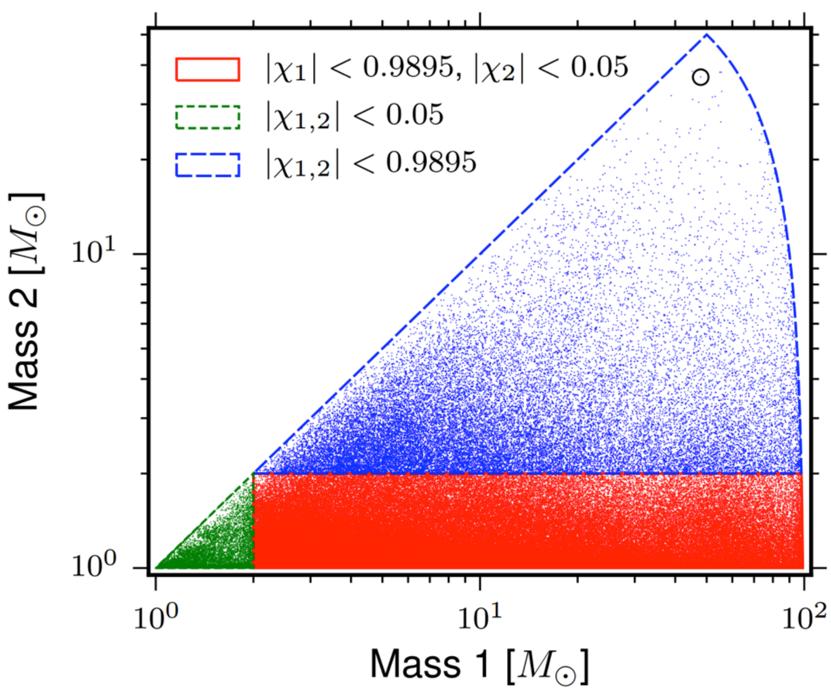

Frequency (Hz)
512
256
128
64
32
LIGO Hanford
512
256
128
64
32
LIGO Livingston
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)
Audio Credit: Caltech/MIT/LIGO Lab

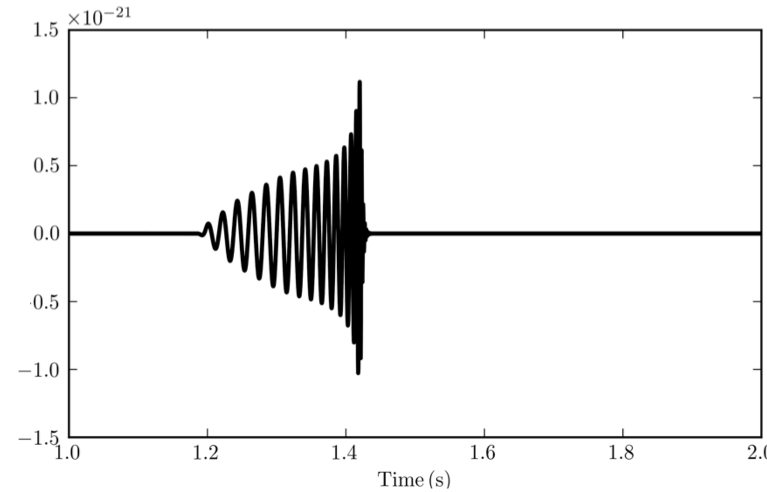
Searching for a specific waveform

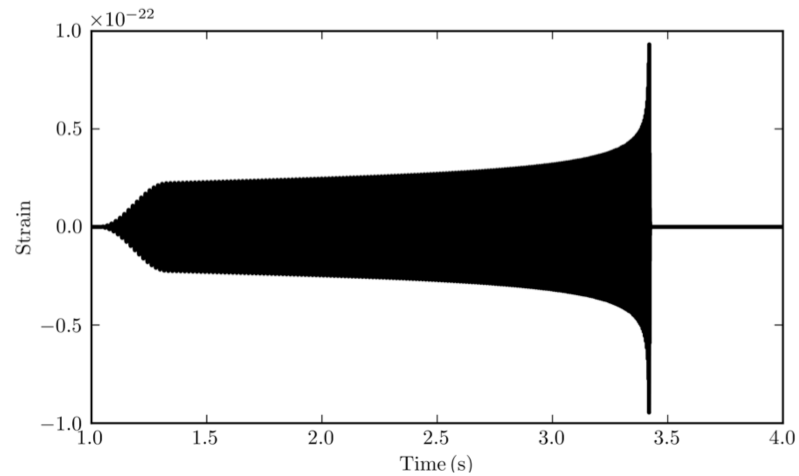


Searching for CBC waveforms

- Use GR predicted waveforms
- Convolve waveforms with data
- Demand coincidence between detectors
- Reject glitches w/ consistency checks



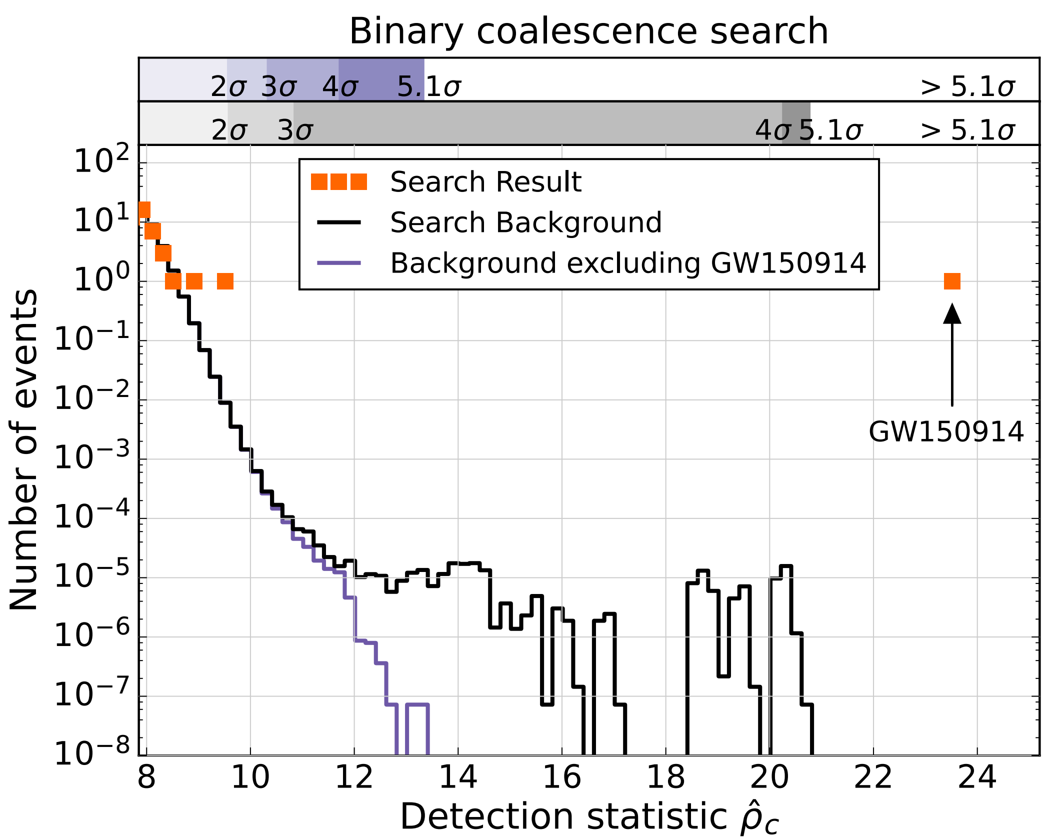




Finding CBC waveforms

Event	Time (UTC)	FAR (yr^{-1})	$\mathscr{F}$	$\mathscr{M}$ ($M_\odot$)	m_1 ($M_\odot$)	m_2 ($M_\odot$)	χ_{eff}	D_L (Mpc)
GW150914	14 September 2015 09:50:45	$< 5 \times 10^{-6}$	$< 2 \times 10^{-7}$ ($> 5.1\,\sigma$)	28^{+2}_{-2}	36^{+5}_{-4}	29^{+4}_{-4}	$-0.06^{+0.17}_{-0.18}$	410^{+160}_{-180}

arXiv:1602.03839

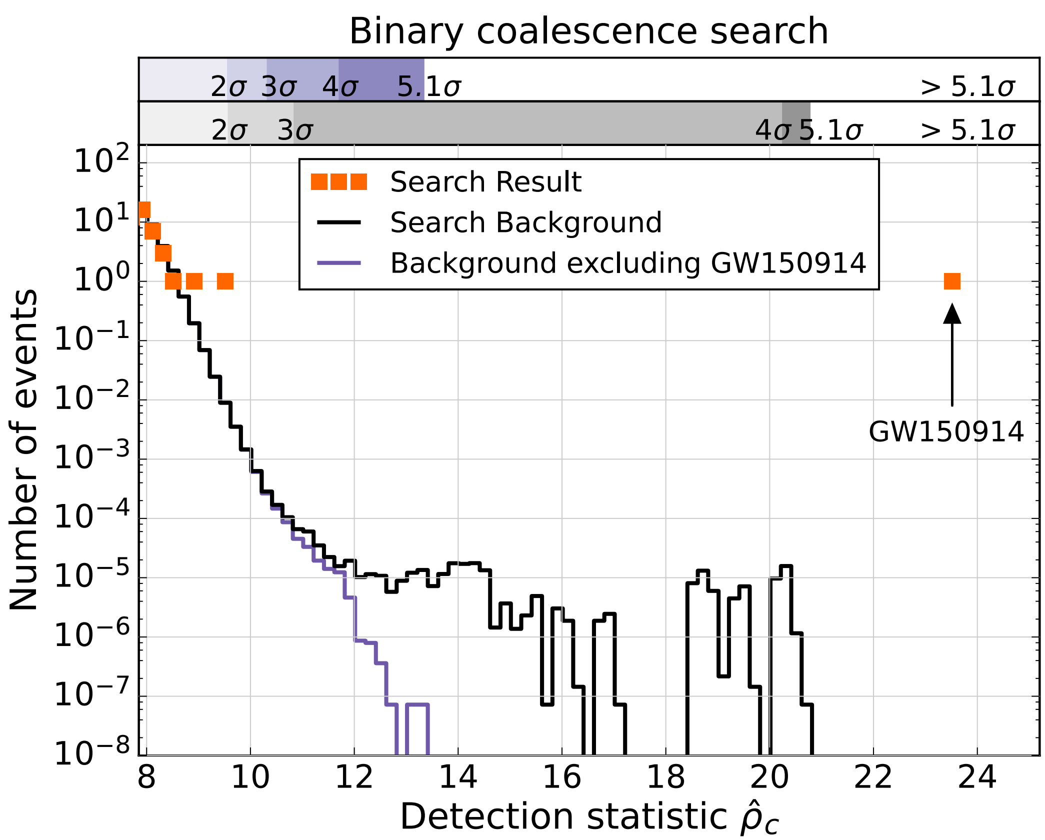


PRL 116, 061102 (2016)

Finding CBC waveforms

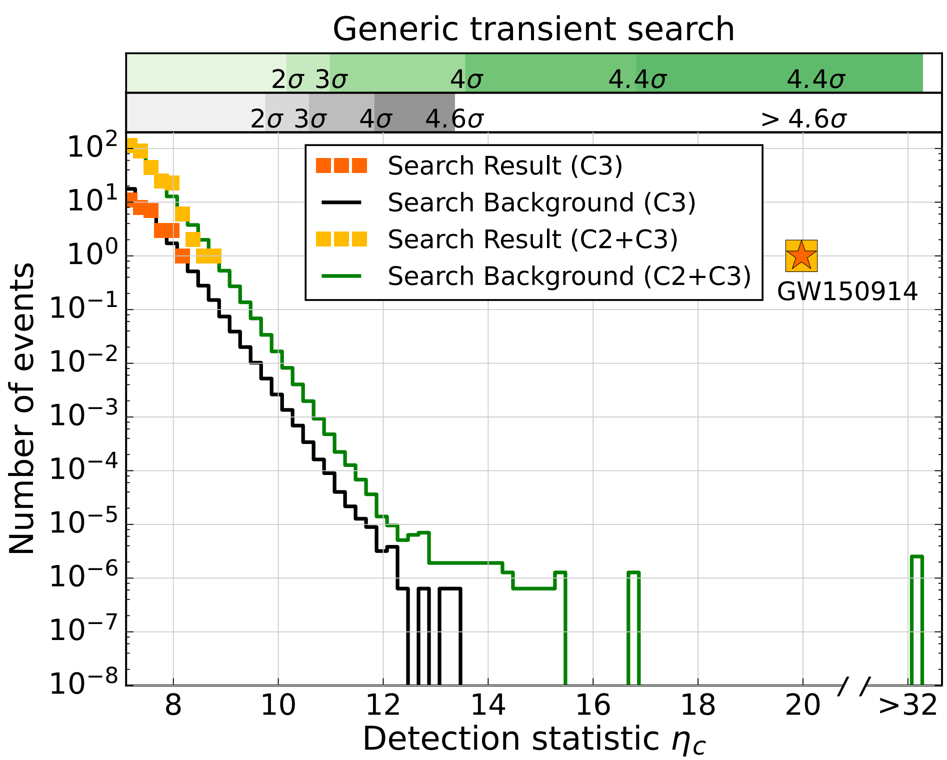
Event	Time (UTC)	FAR (yr^{-1})	$\mathscr{F}$	$\mathscr{M}$ ($M_\odot$)	m_1 ($M_\odot$)	m_2 ($M_\odot$)	χ_{eff}	D_L (Mpc)
GW150914	14 September 2015 09:50:45	$< 5 \times 10^{-6}$	$< 2 \times 10^{-7}$ ($> 5.1\,\sigma$)	28^{+2}_{-2}	36^{+5}_{-4}	29^{+4}_{-4}	$-0.06^{+0.17}_{-0.18}$	410^{+160}_{-180}
LVT151012	12 October 2015 09:54:43	0.44	0.02 ($2.1\,\sigma$)	15^{+1}_{-1}	23^{+18}_{-5}	13^{+4}_{-5}	$0.0^{+0.3}_{-0.2}$	1100^{+500}_{-500}

arXiv:1602.03839

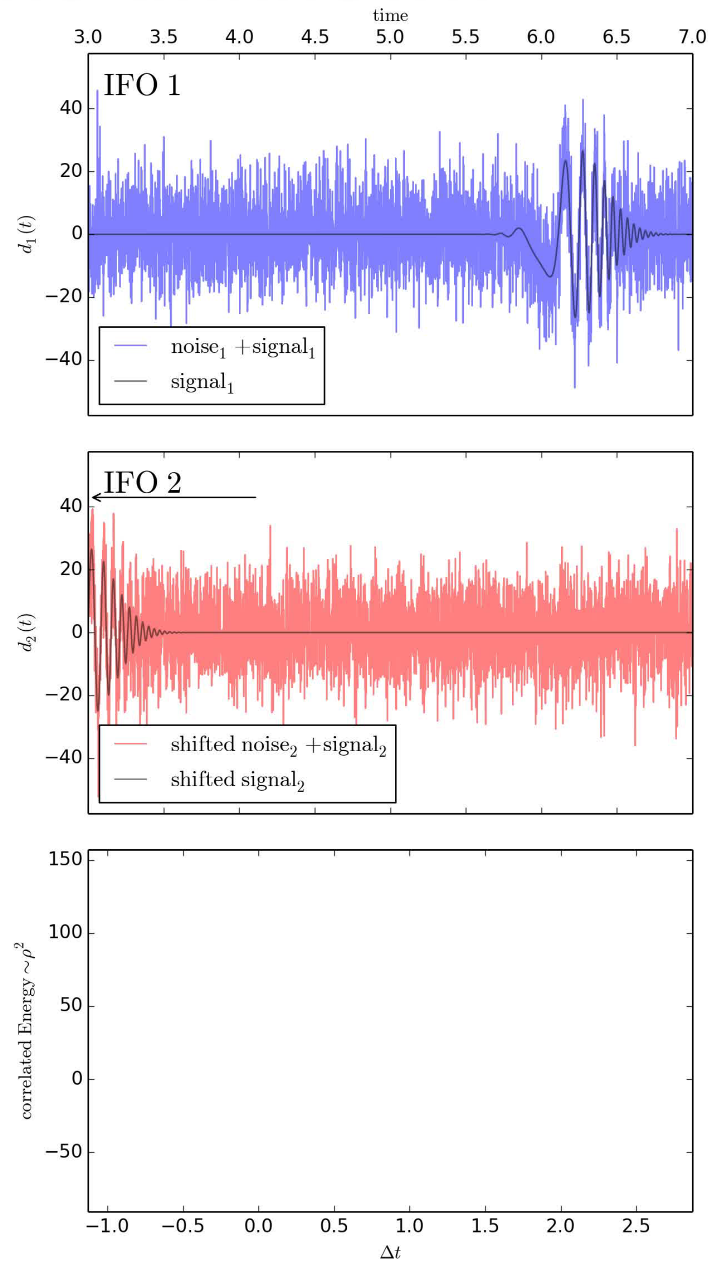


PRL 116, 061102 (2016)

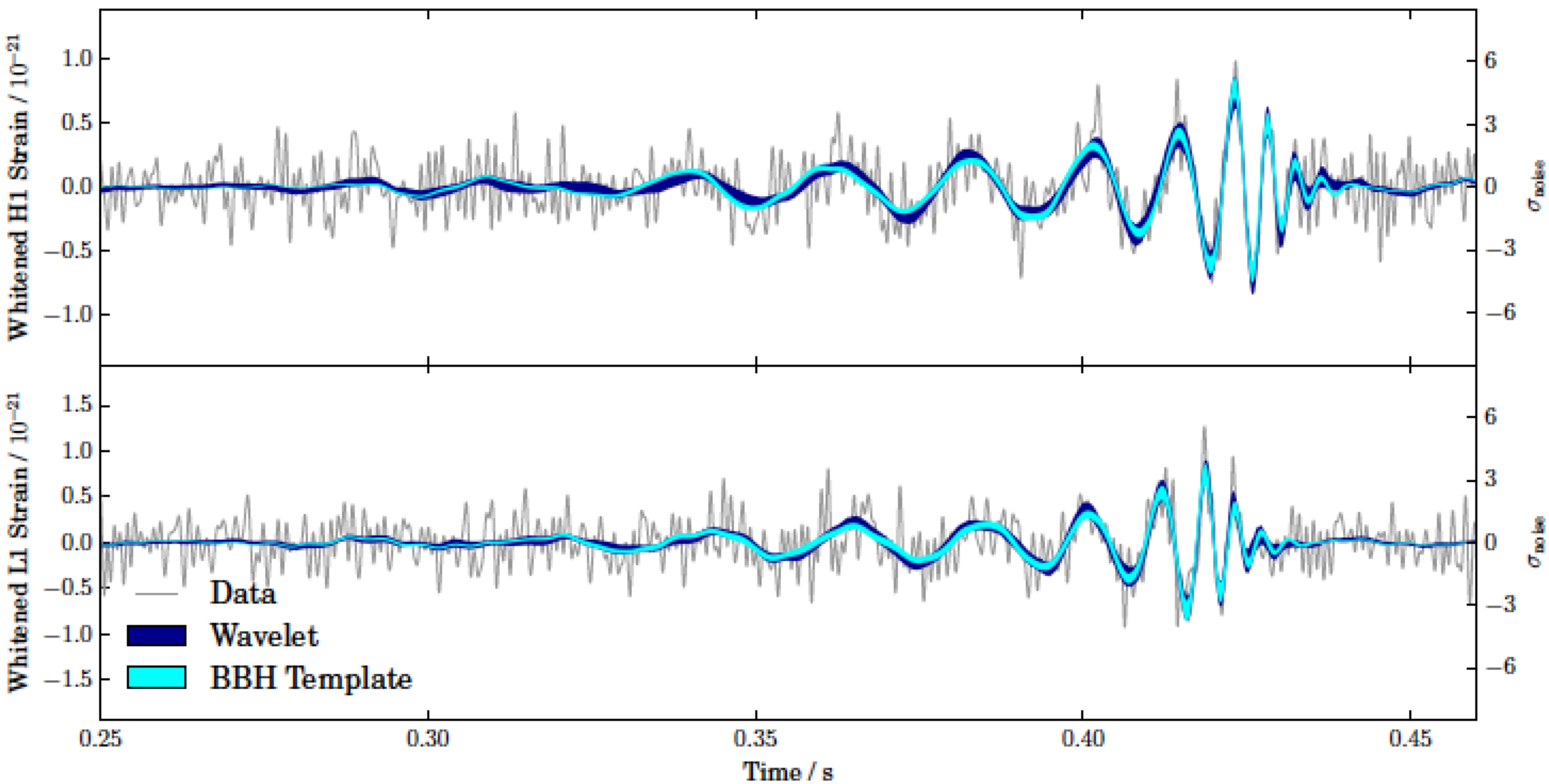
Searching for the unknown



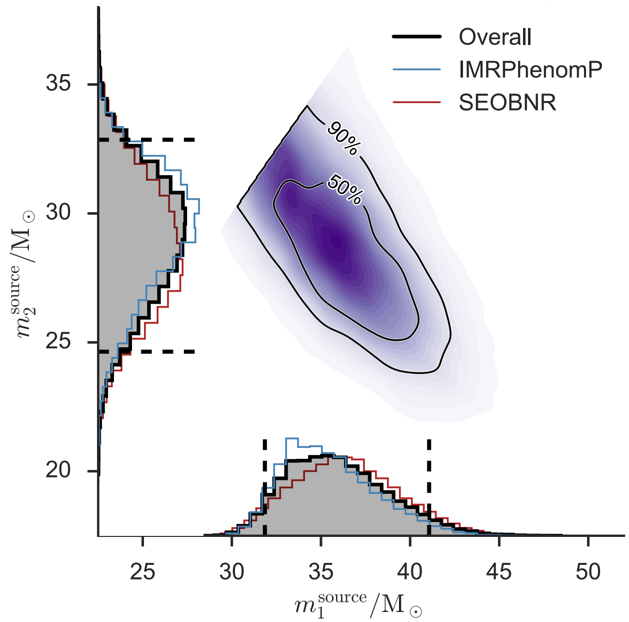
PRL 116, 061102 (2016)

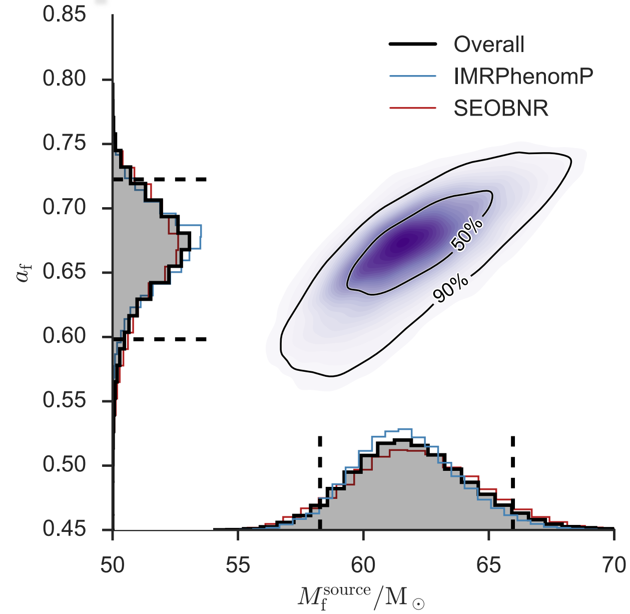


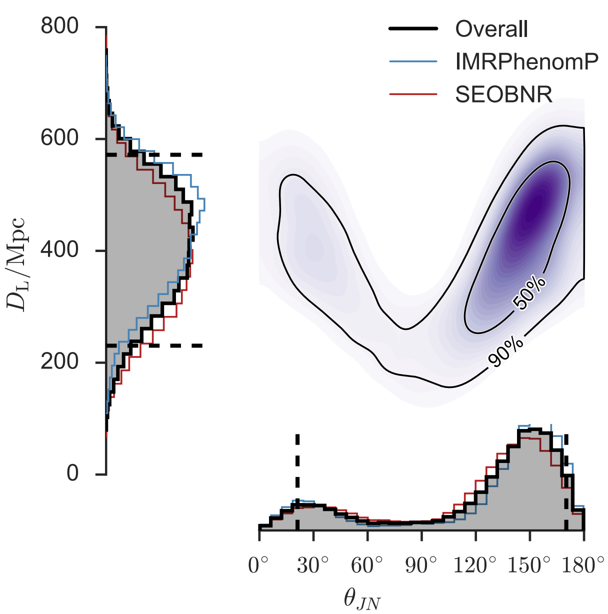
Detected waveform

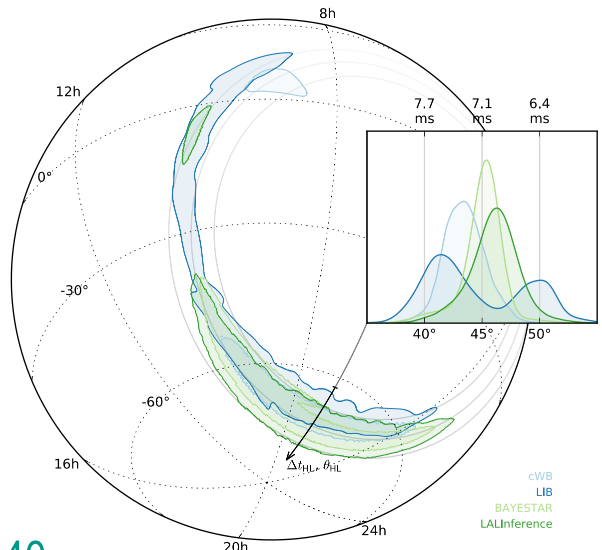


GW150914 parameters

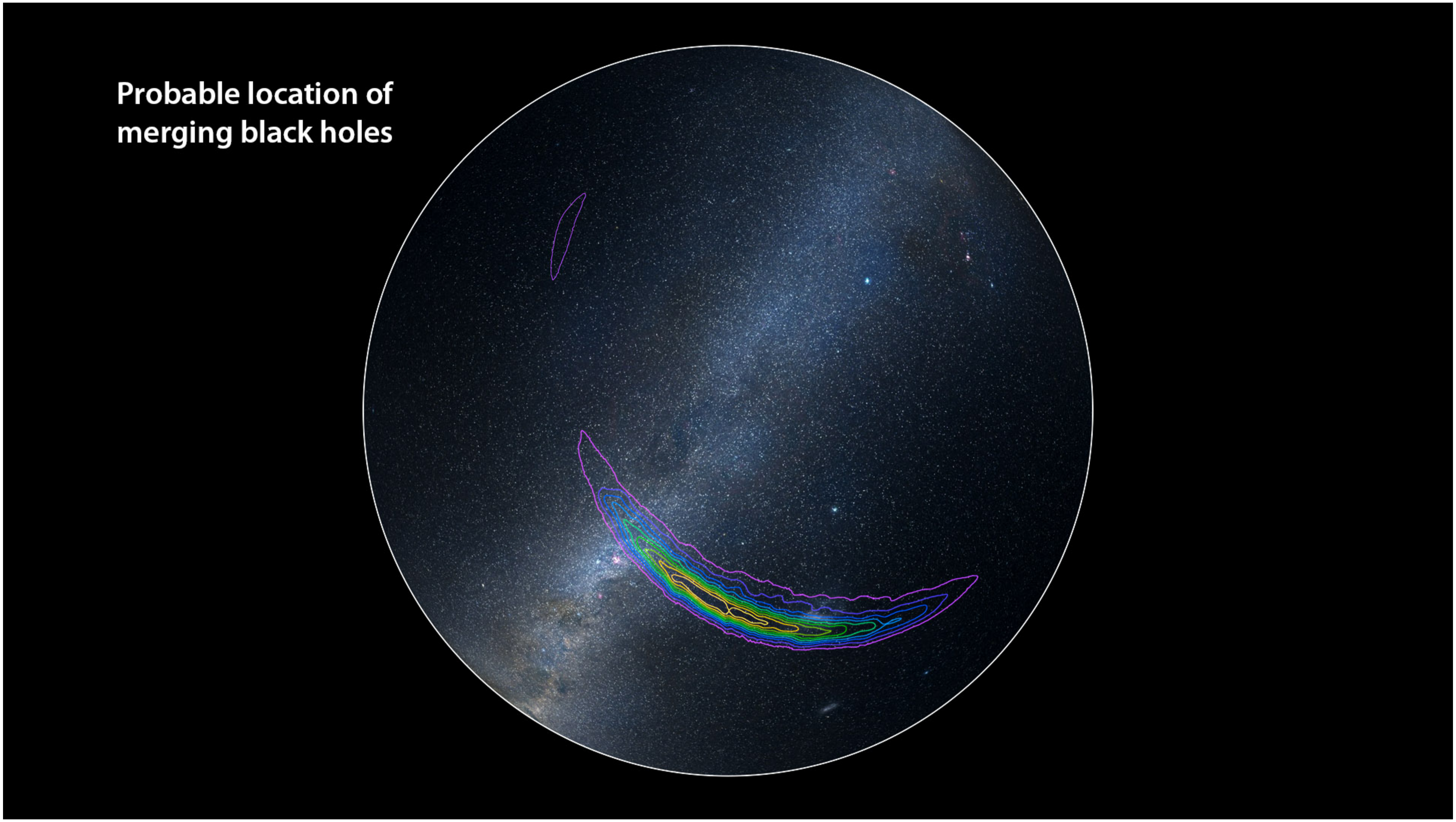




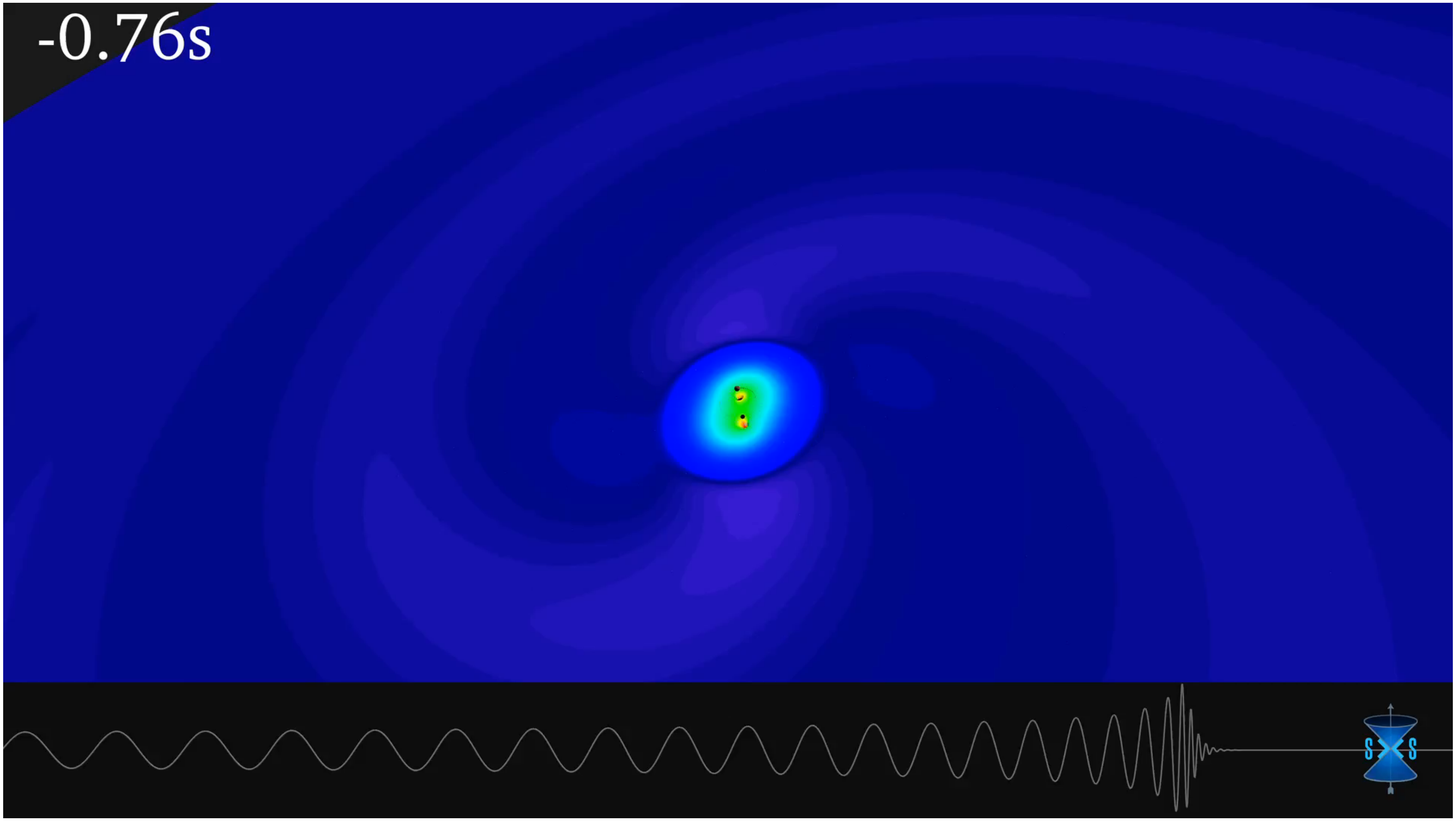




arXiv:1602.03840


Probable location of
merging black holes

Binary black hole waveform

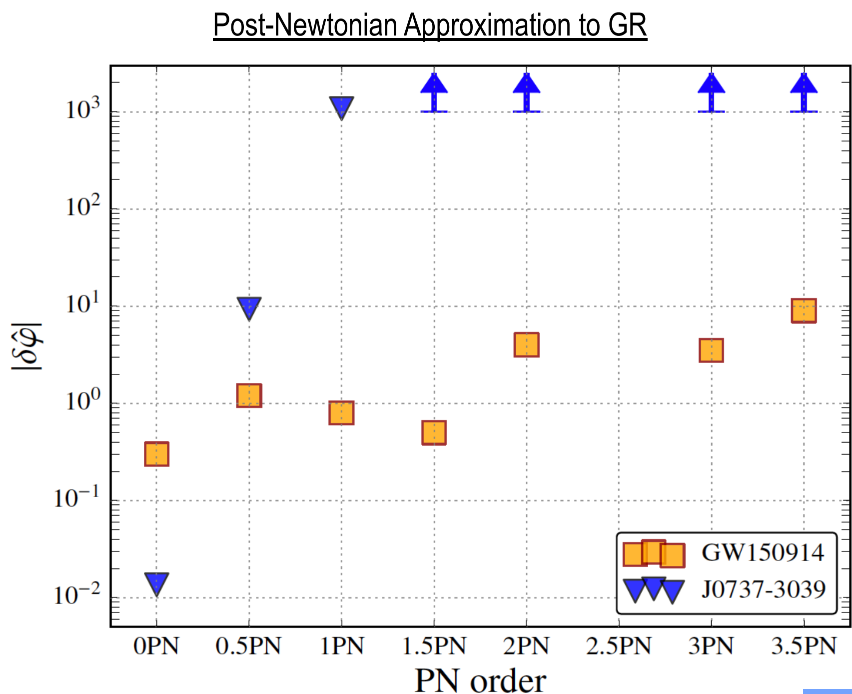


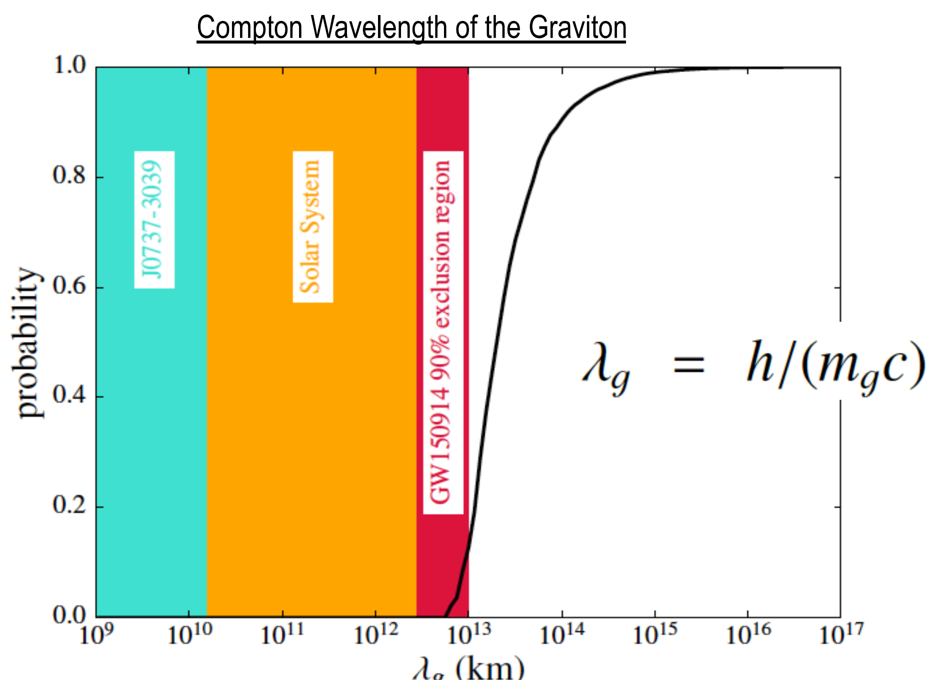
Credit: SXS

What GW150914 Tells Us About the Validity of General Relativity

- GW150914 is the first observation of a binary black hole merger…
- … and thus is the best test of GR in *the strong field, dynamical, nonlinear regime*

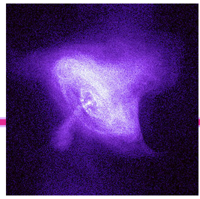
$$m_g \leq 1.2 \times 10^{-22} \text{ eV/c}^2 \text{ at } 90\% \text{ confidence}$$



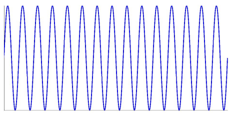


Abbott, et al. ,LIGO Scientific Collaboration and Virgo Collaboration, "Tests of general relativity with GW150914", http://arxiv.org/abs/1602.03841

Discovery space: not just BBHs!

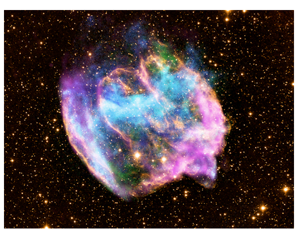


Crab pulsar (NASA, Chandra Observatory)

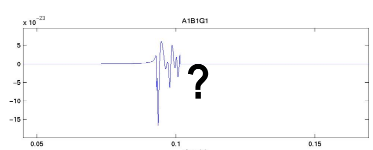


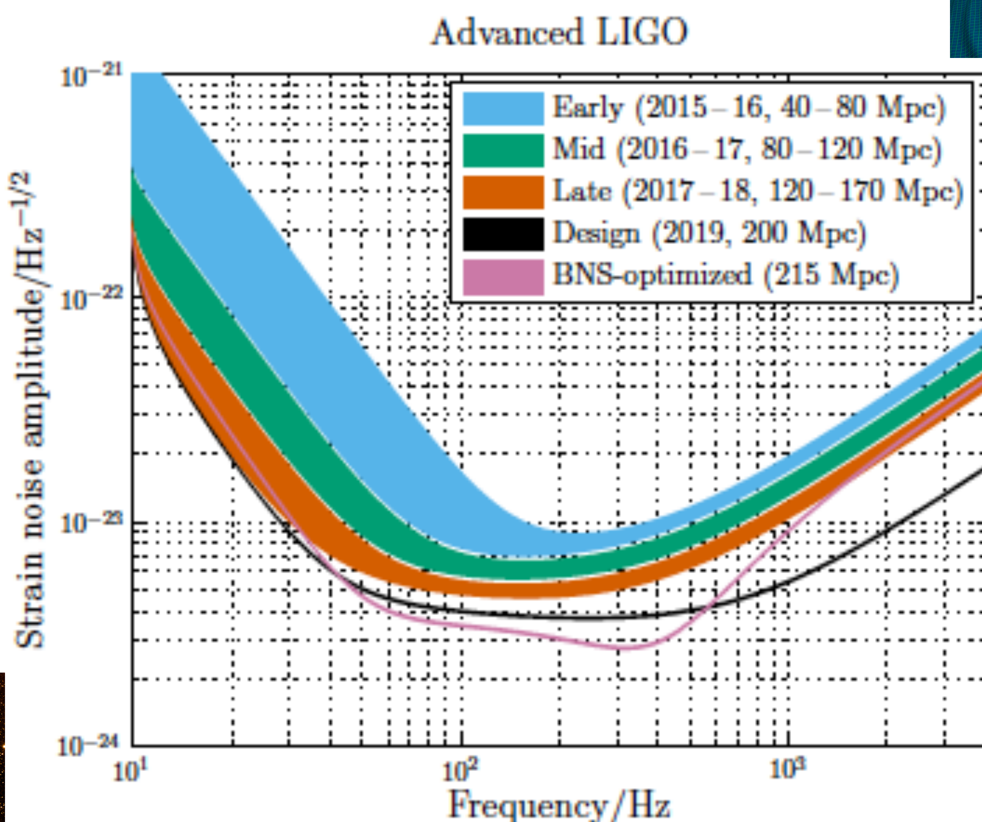
Continuous, periodic waves

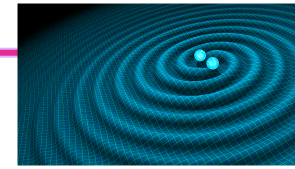
Generic transients
Supernovae



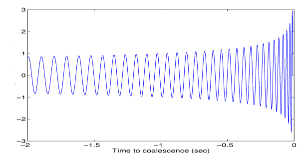
W49B composite;
X-ray: NASA/CXC/MIT/L.Lopez et al.;
Infrared: Palomar; Radio: NSF/NRAO/VLA





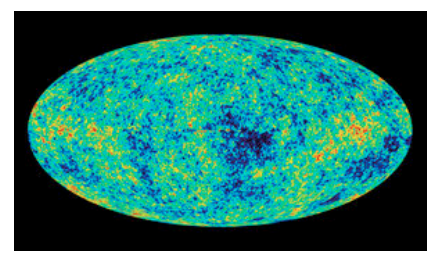


JPL/NASA

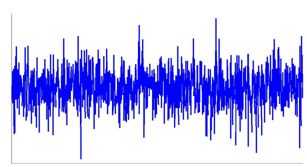


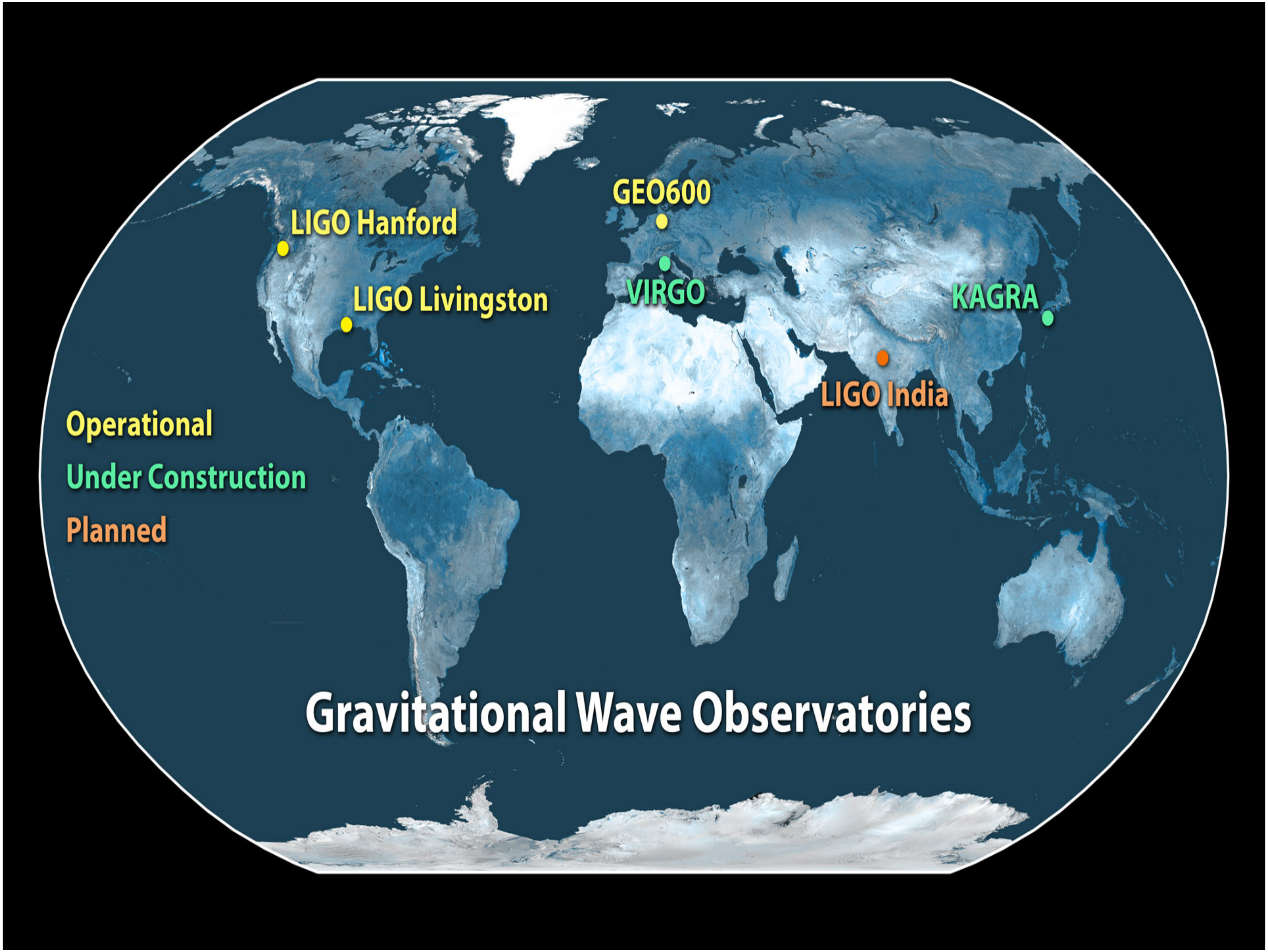
Binary Neutron Stars
Neutron Star- Black Hole binary systems
Binary Black Hole systems

Stochastic background (astrophysical > cosmological)



NASA, WMAP




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

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

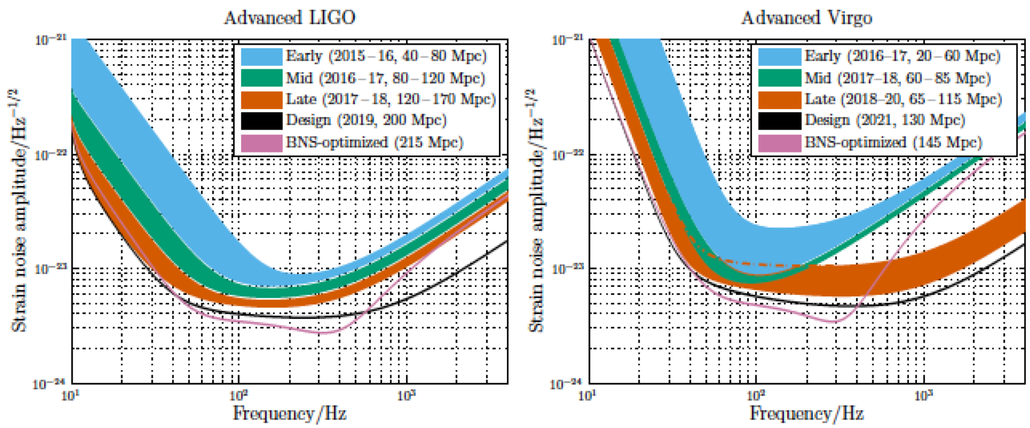


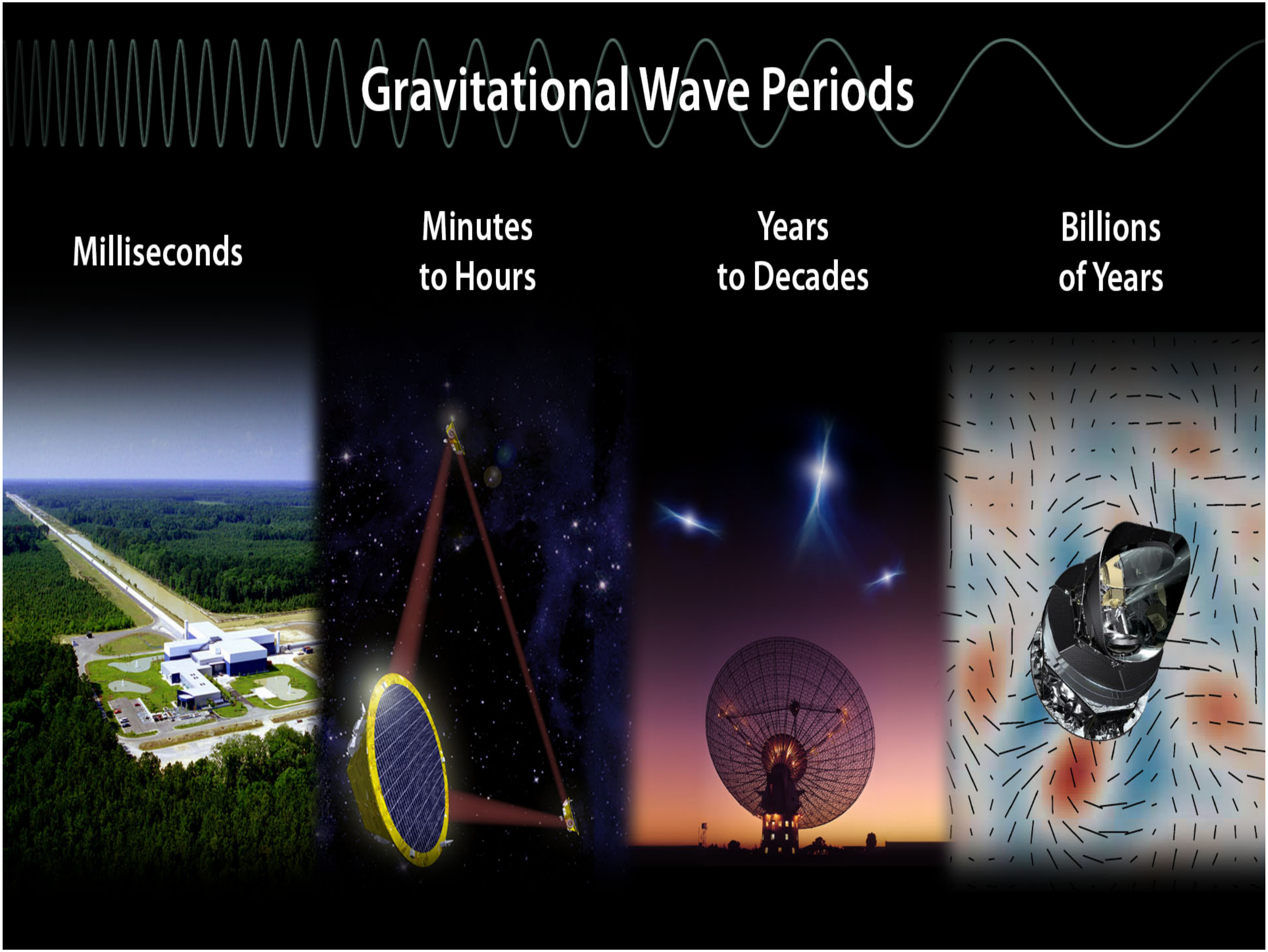
Figure 1: aLIGO (*left*) and AdV (*right*) target strain sensitivity as a function of frequency. The binary neutron-star (BNS) range, the average distance to which these signals could be detected, is given in megaparsec. Current notions of the progression of sensitivity are given for early, mid and late 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.


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

This is only the dawn of gravitational wave astronomy