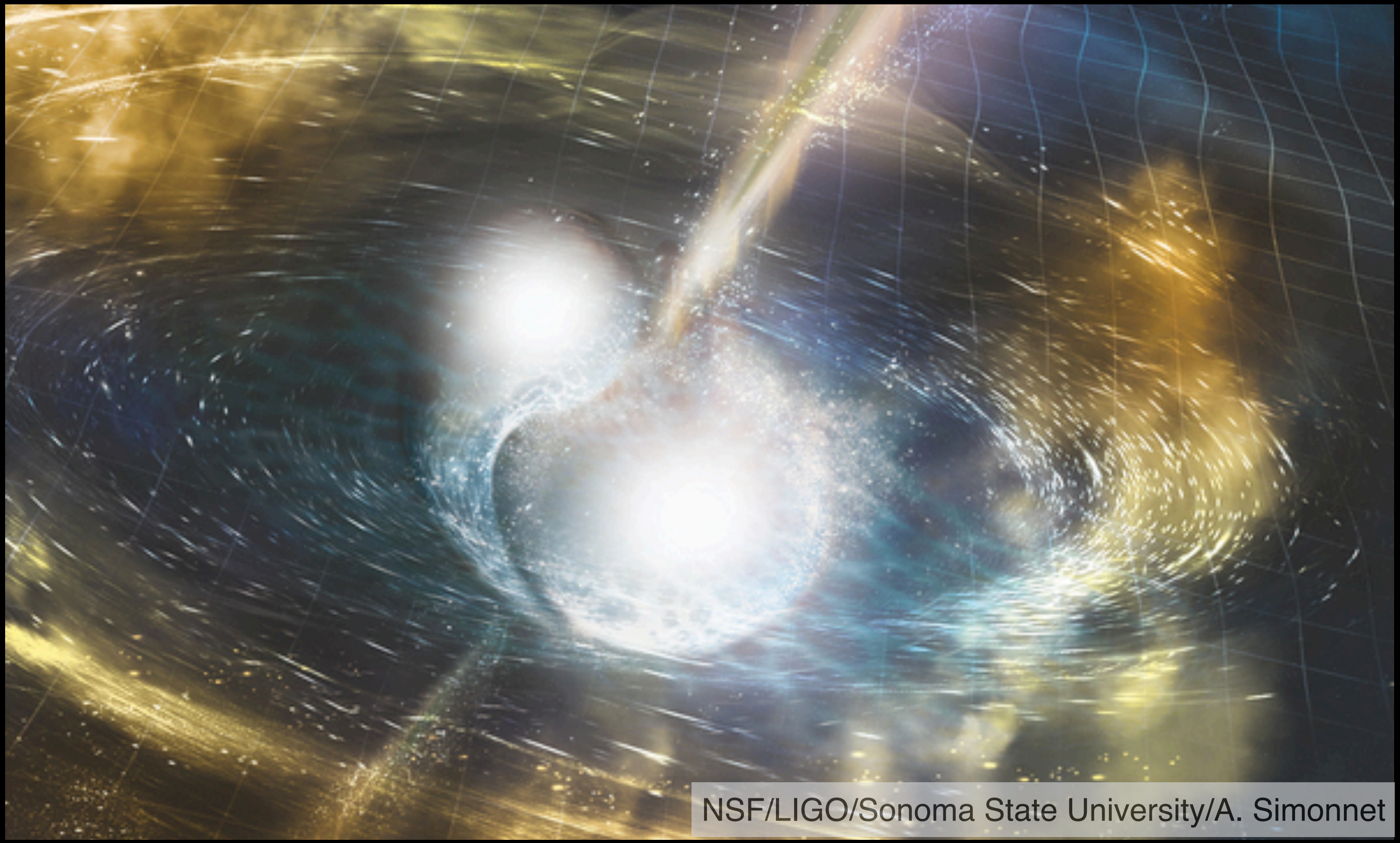
GW170817: gravitational waves from the merger of two neutron stars



Dr. Jess McIver for the LIGO-Virgo Collaboration

Caltech/JPL Association for Gravitational-Wave Research Seminar

Oct 24, 2017

LIGO DCC G1702114

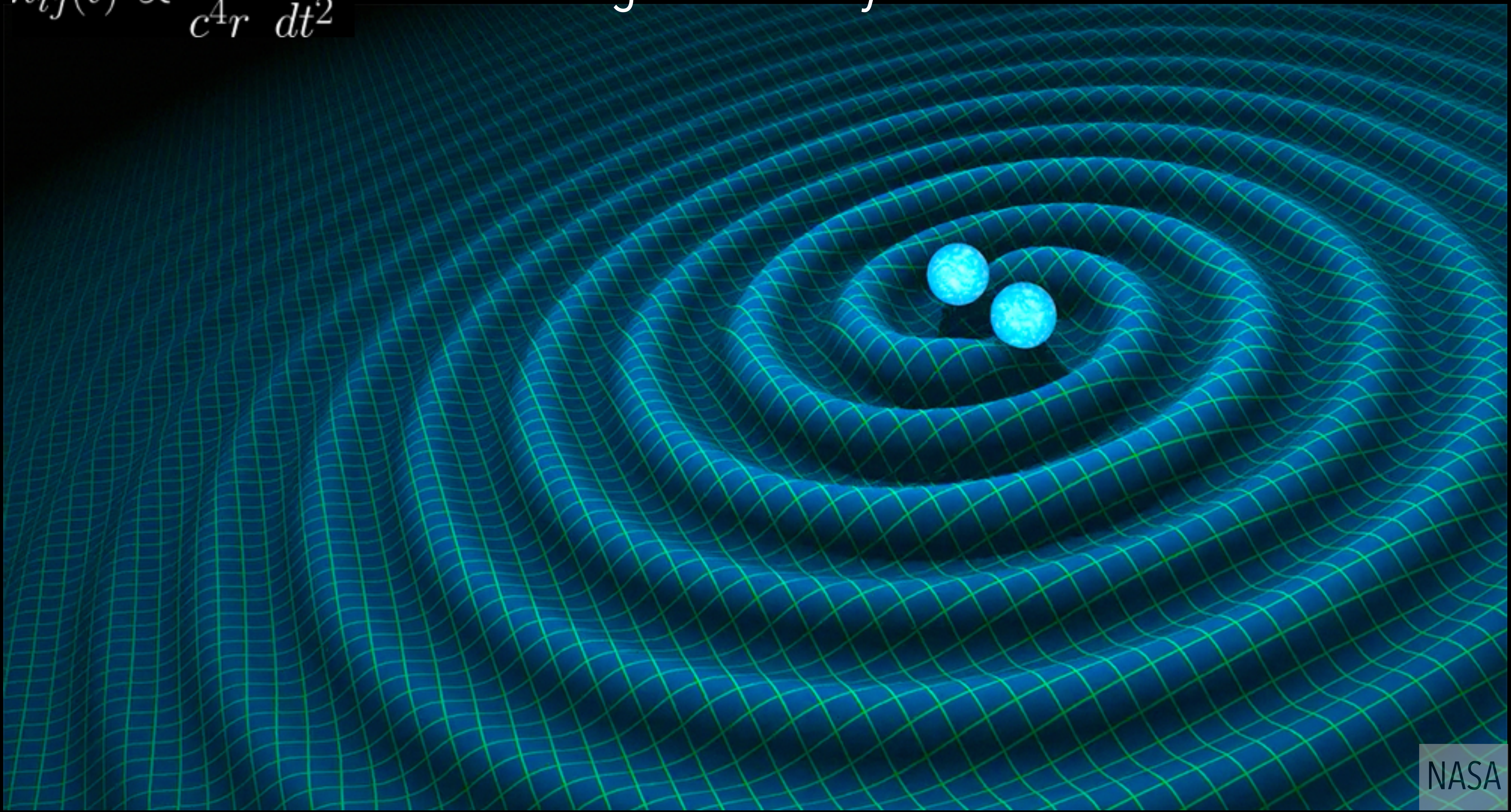
LSC

Caltech

Gravitational waves

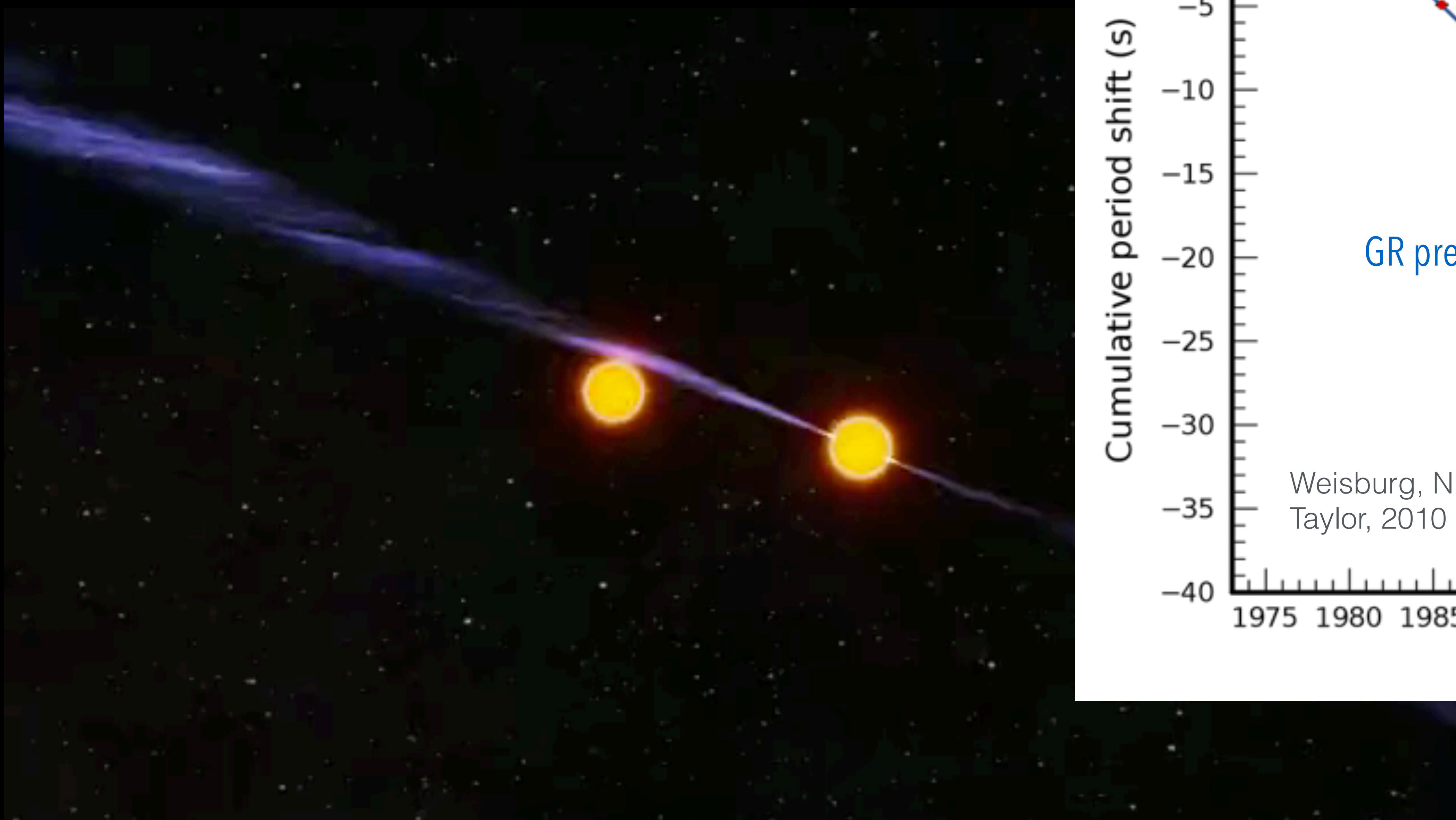
Ripples in the fabric of spacetime
generated by the acceleration of matter

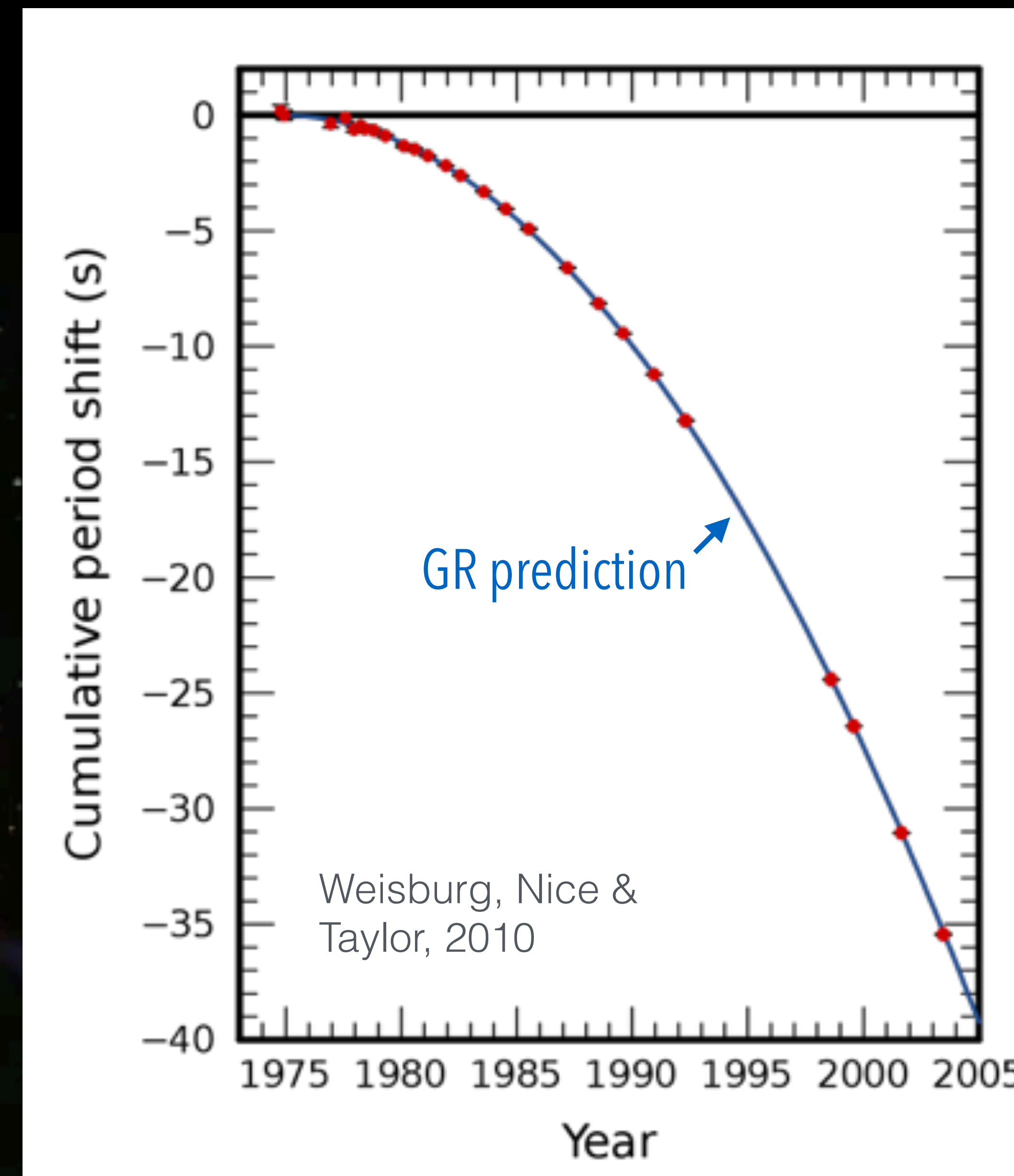
$$h_{ij}(t) \propto \frac{G}{c^4 r}\frac{d^2 I_{ij}}{dt^2}$$



Indirect evidence of gravitational waves

Hulse-Taylor Binary Pulsar
PSR B1913+16

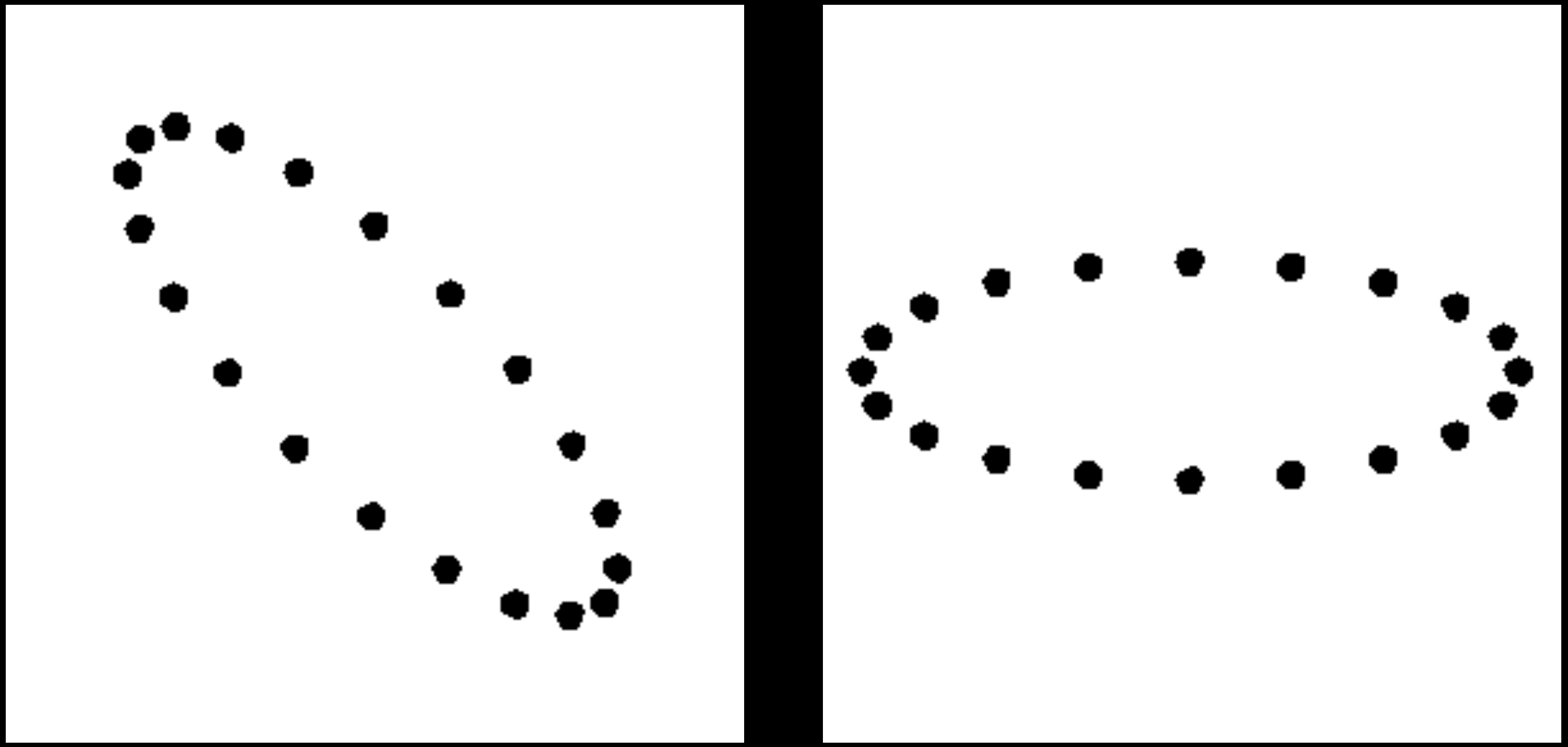




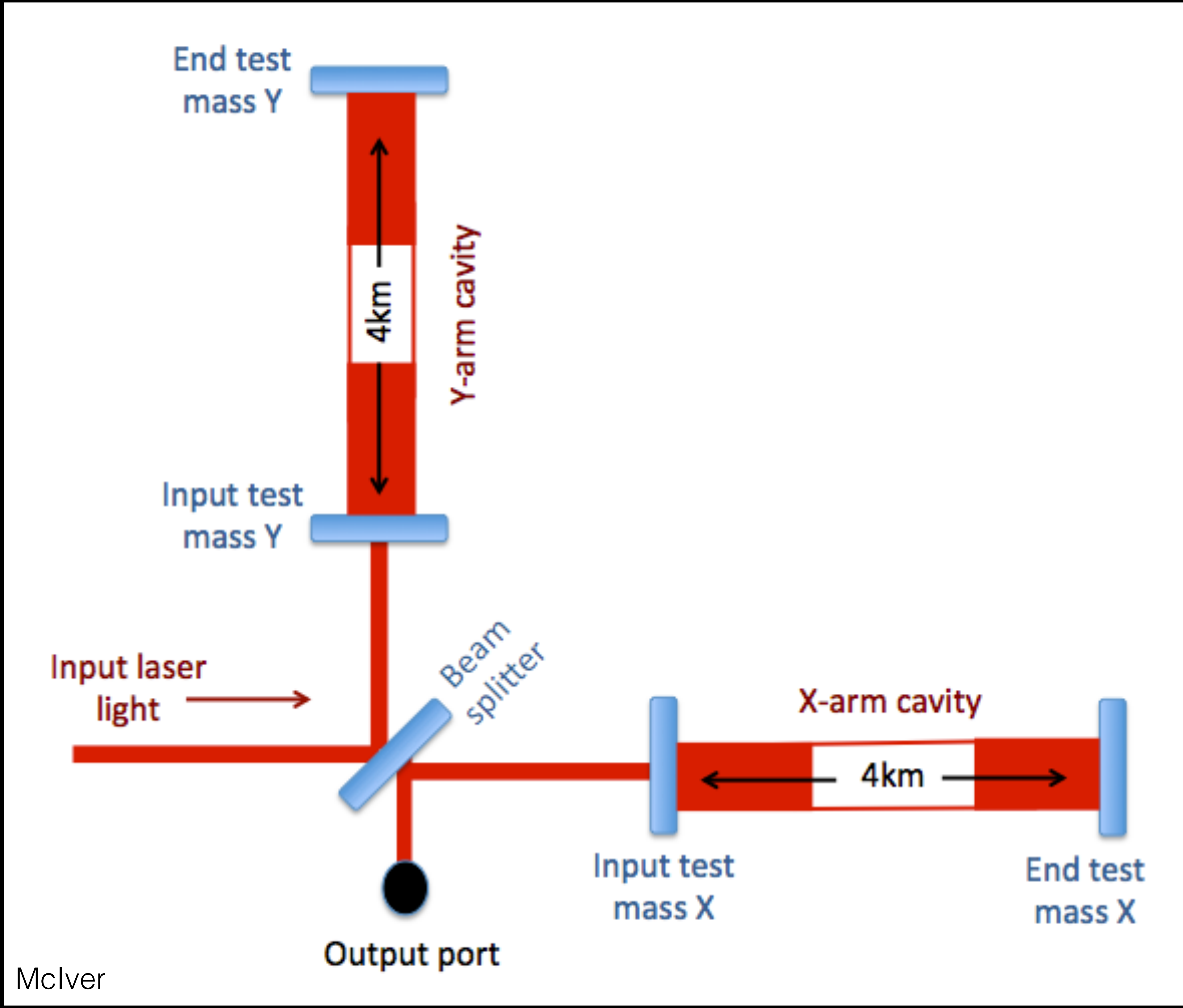
Gravitational wave propagation

$$h(t) = Ae^{i(2\pi ft - \mathbf{k}\cdot\mathbf{r})}$$

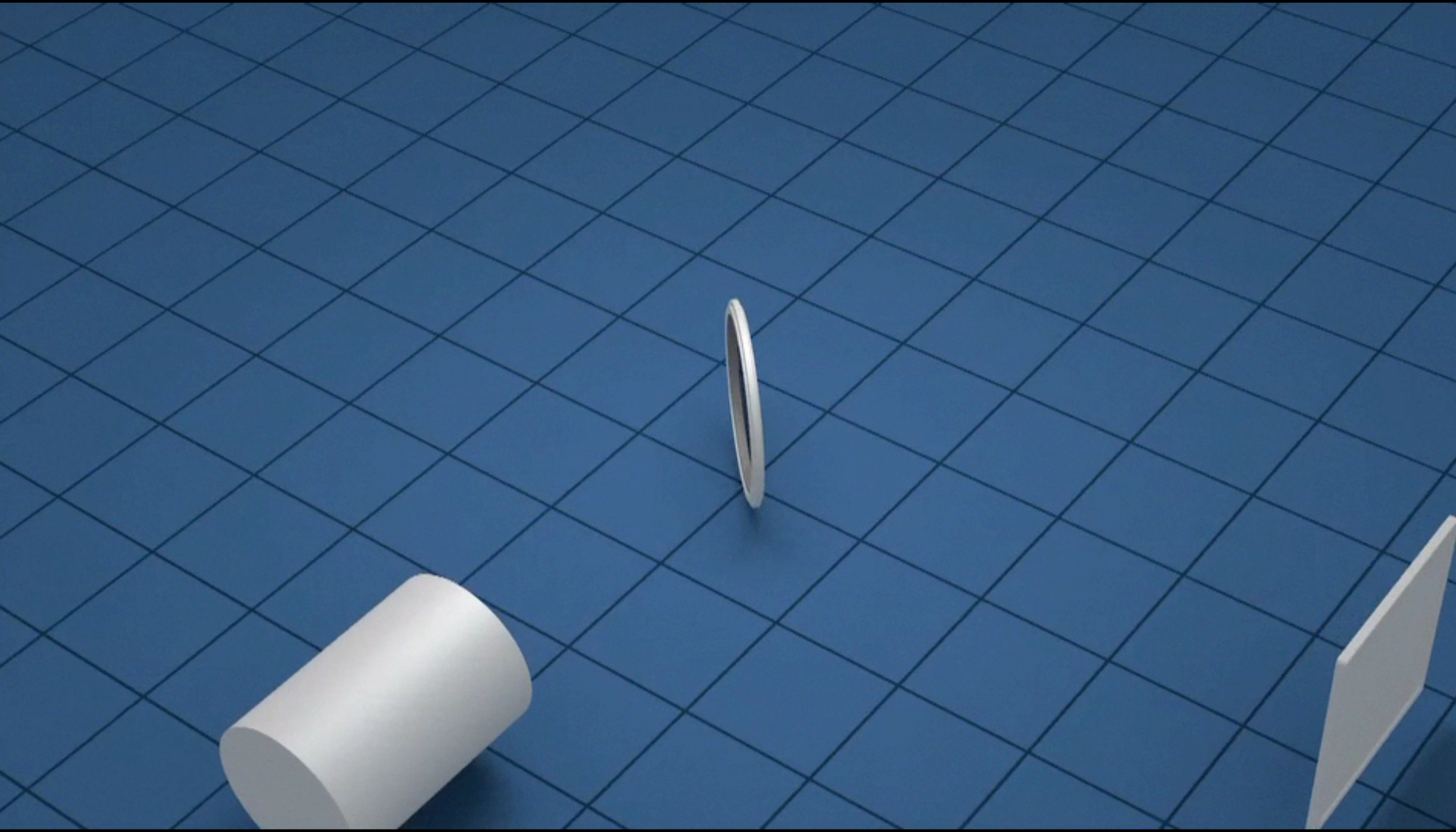
Spacetime strain h(t) measured as $\frac{\Delta L}{L}$



Observing GWs with interferometry



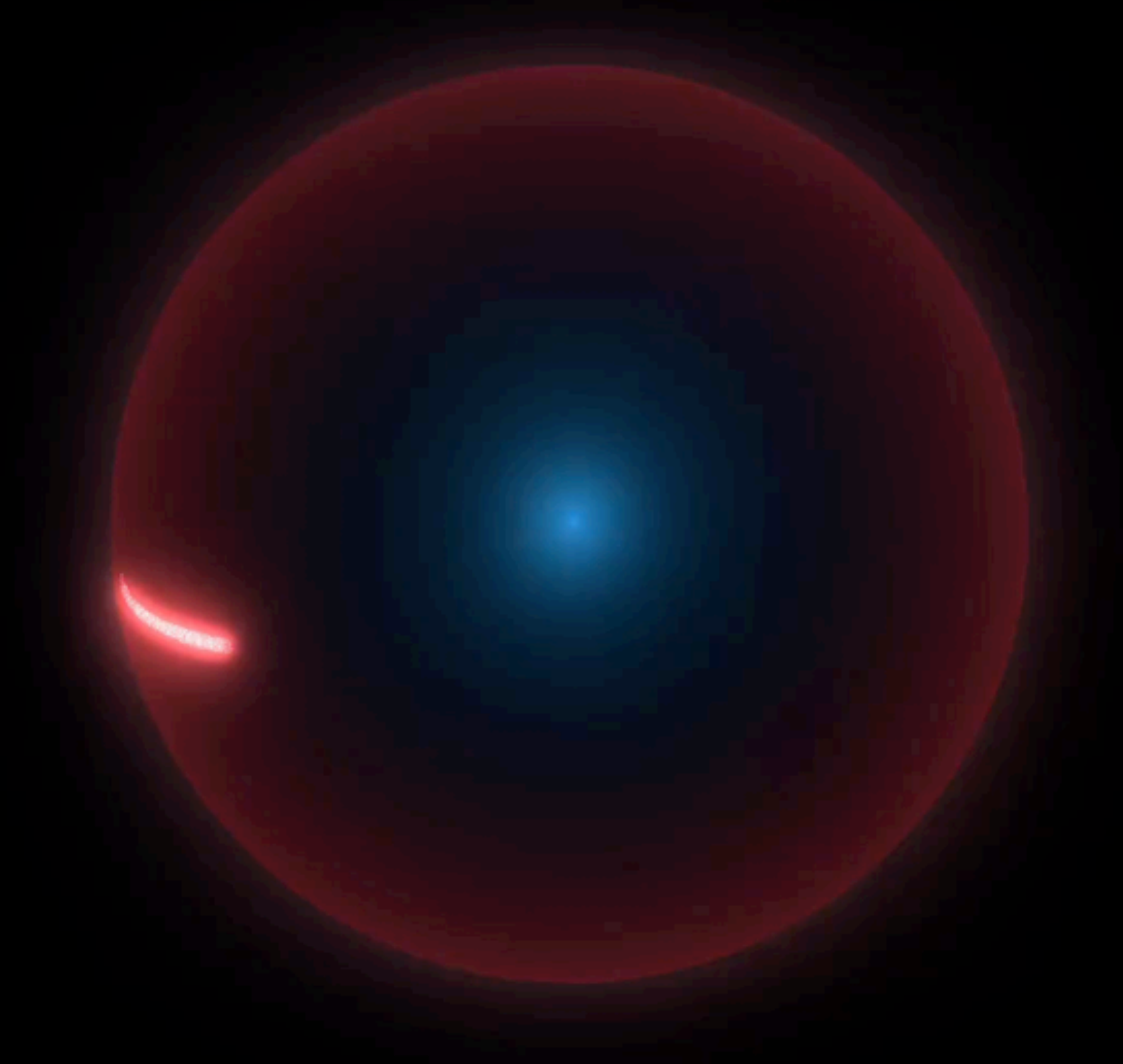
How does LIGO detect gravitational waves?



LIGO/Caltech

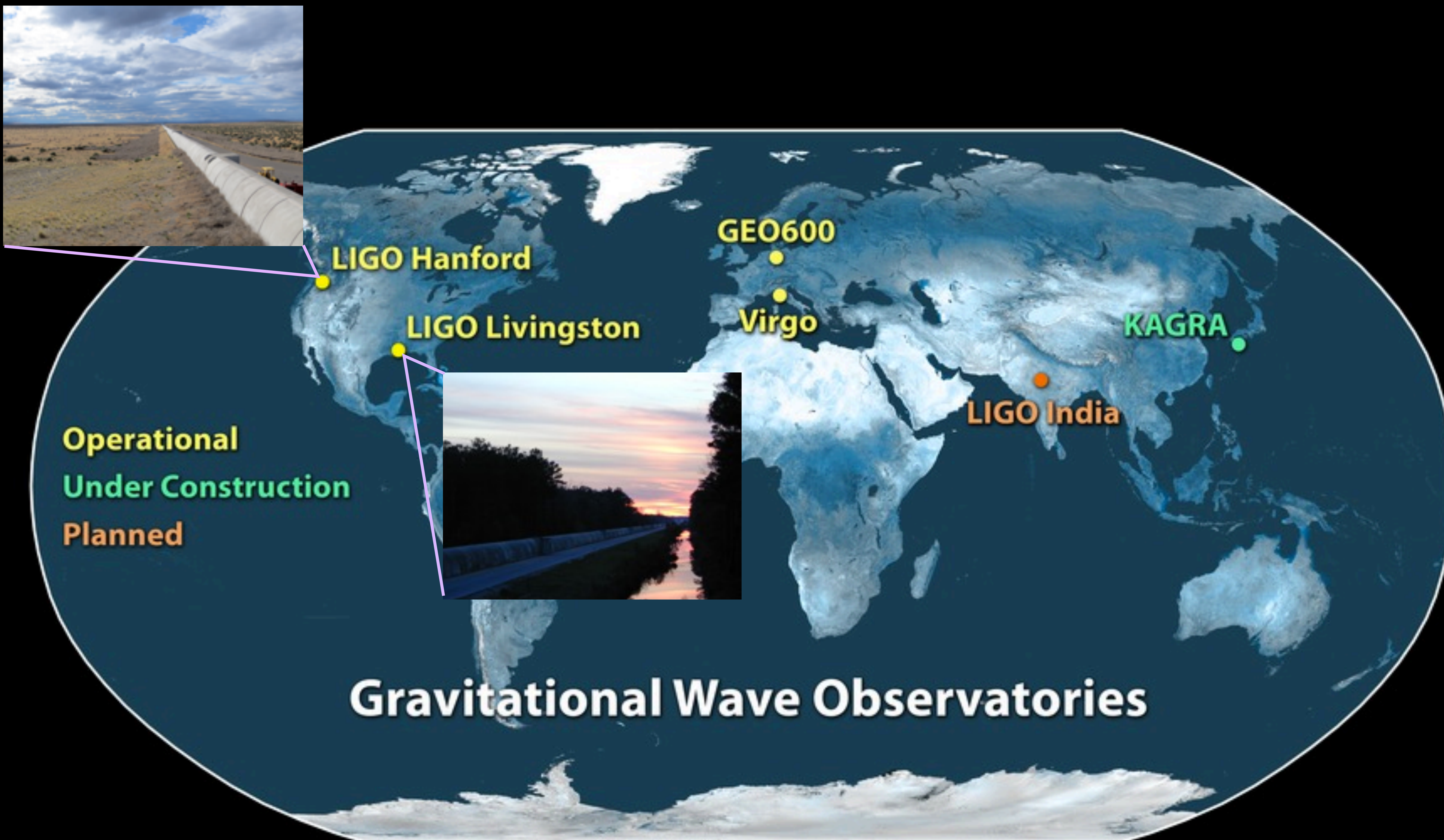
Kai Staats

How sensitive is the LIGO experiment?



LIGO/Caltech

Where are the LIGO detectors?

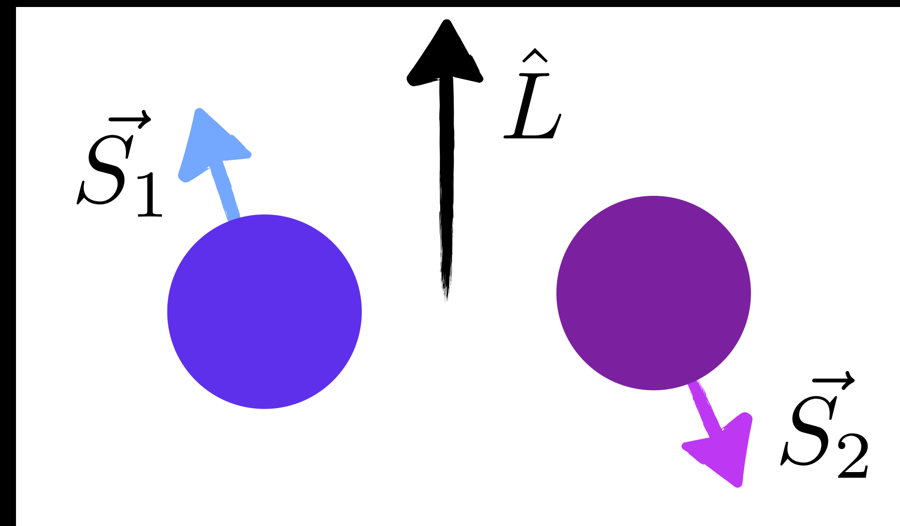


LIGO/Caltech

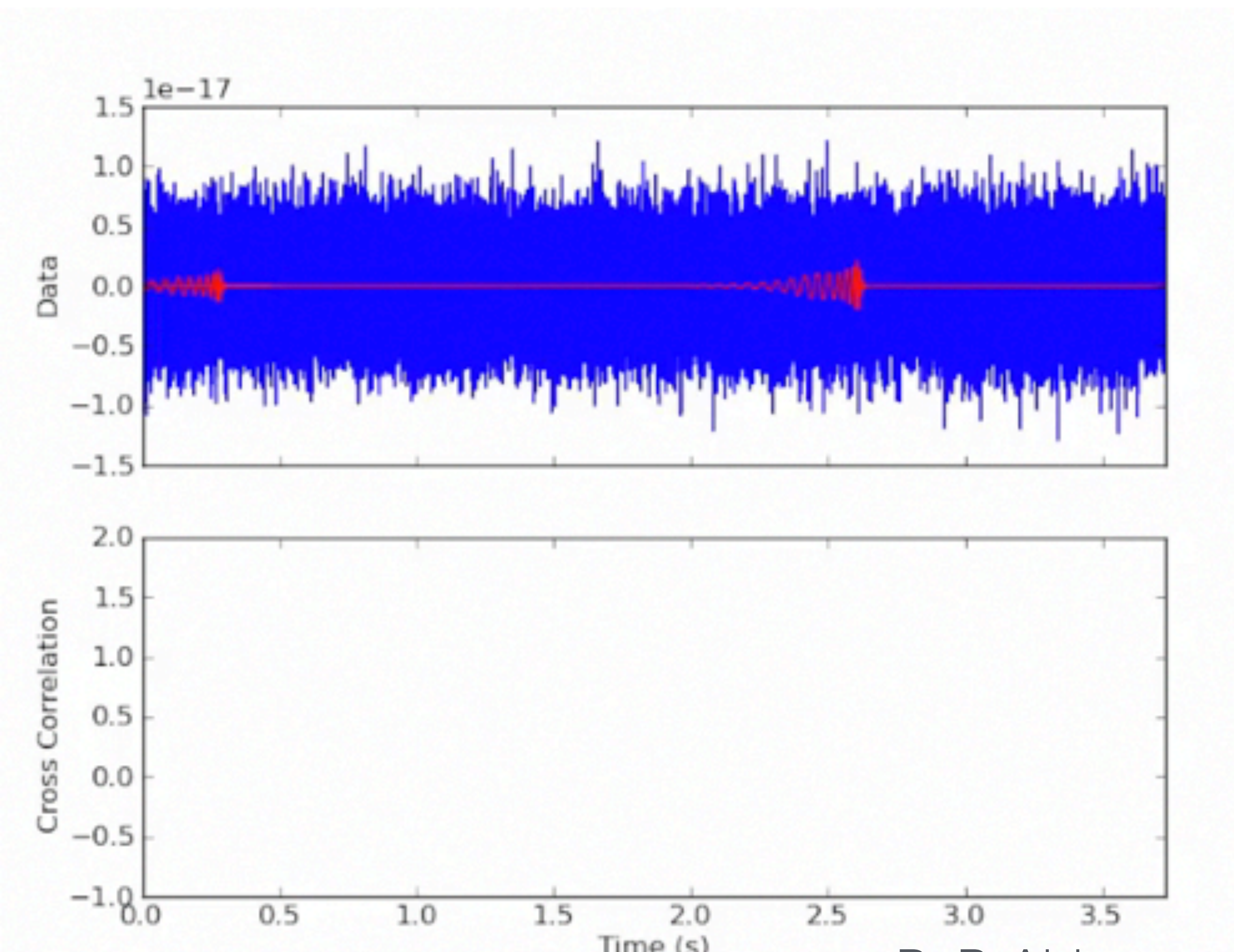
Matched Filter Analysis

Slide adapted from S. Caudill

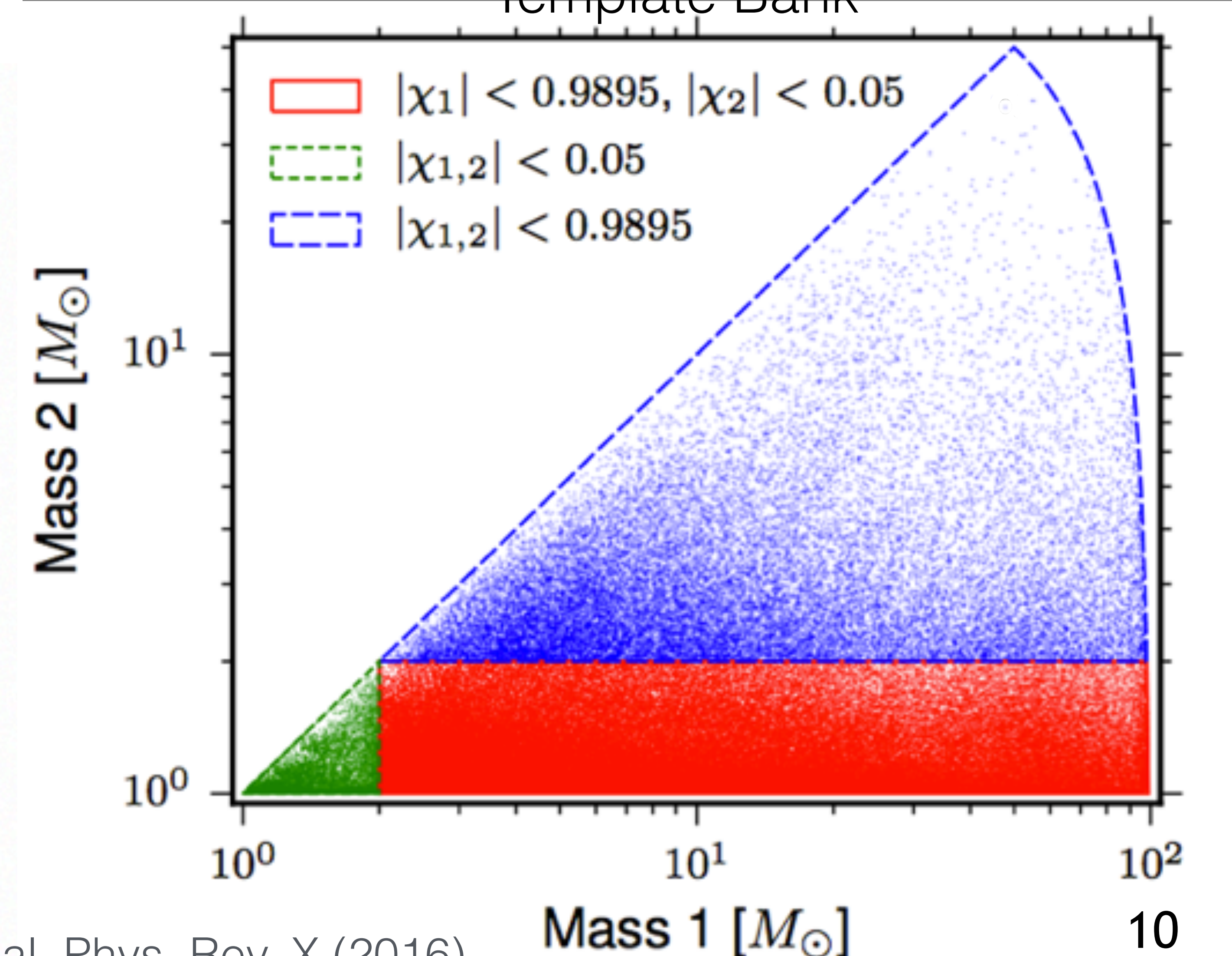
$$\chi_{1,2} \propto \vec{S_{1,2}} \cdot \hat{L}$$



Matched filter signal-to-noise ratio



Template Bank

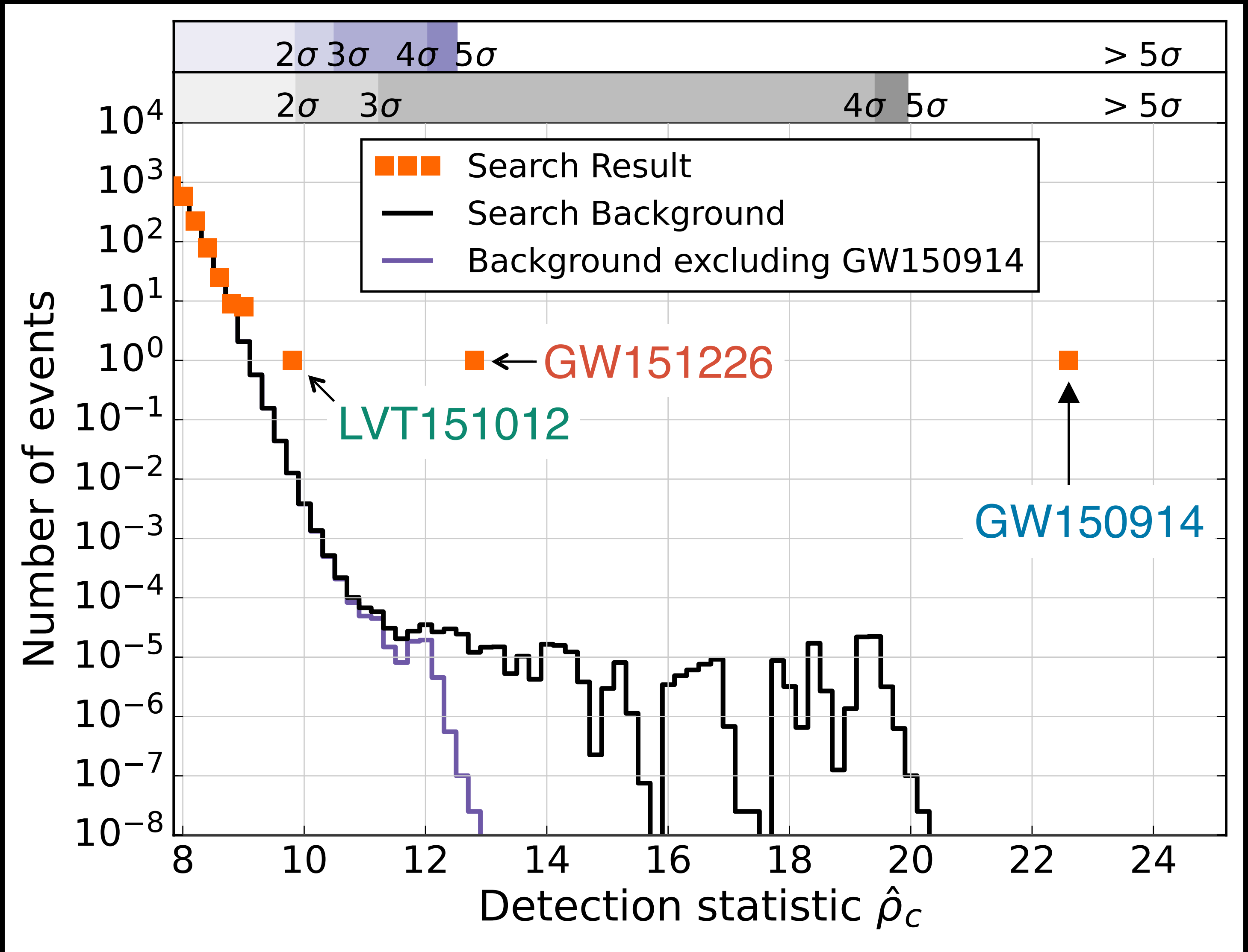


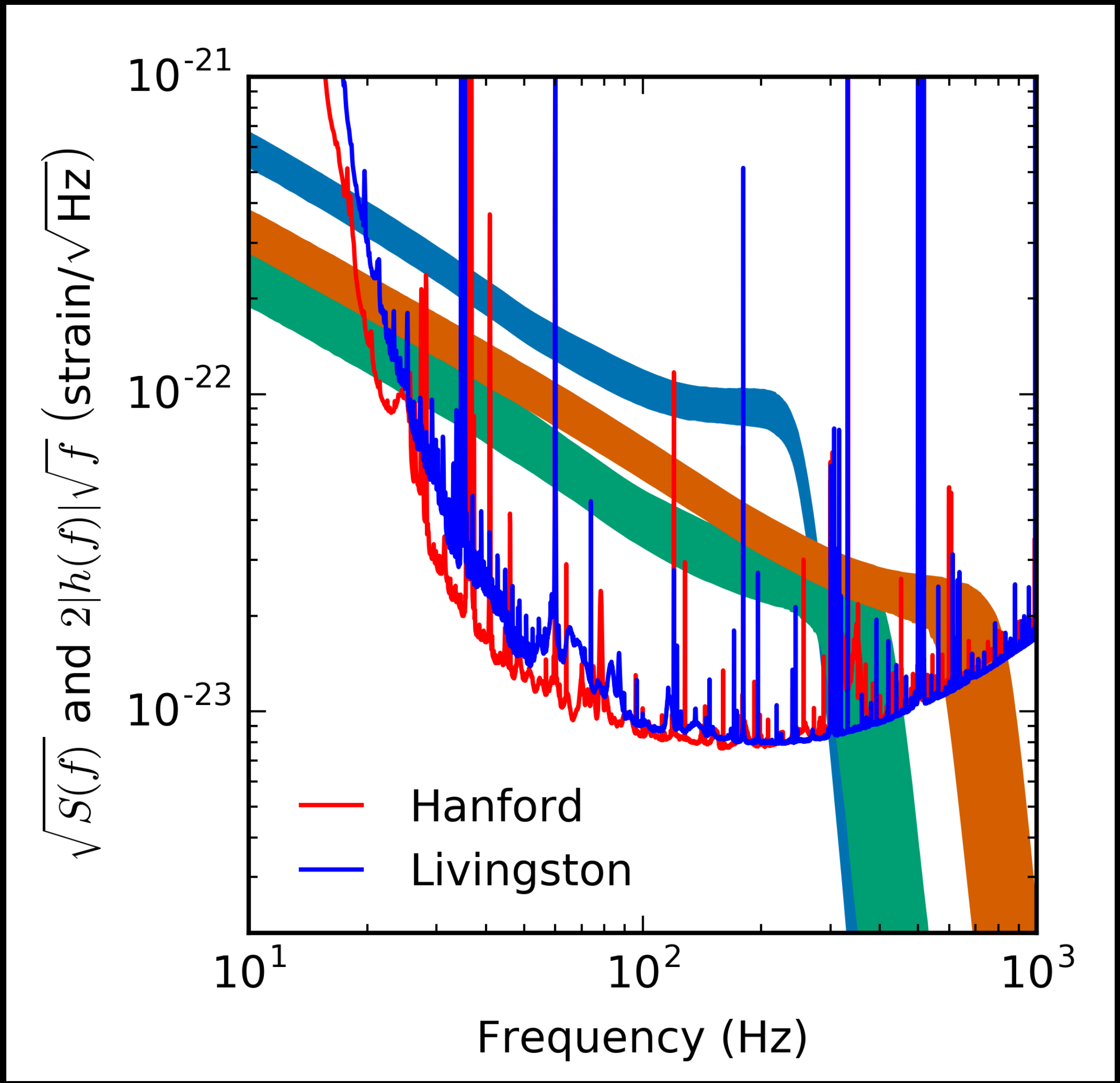
B. P. Abbott et al. Phys. Rev. X (2016)

O1 results

$$\rho^2(t) = \left[\langle s|h_c\rangle^2(t) + \langle s|h_s\rangle^2(t)\right]$$

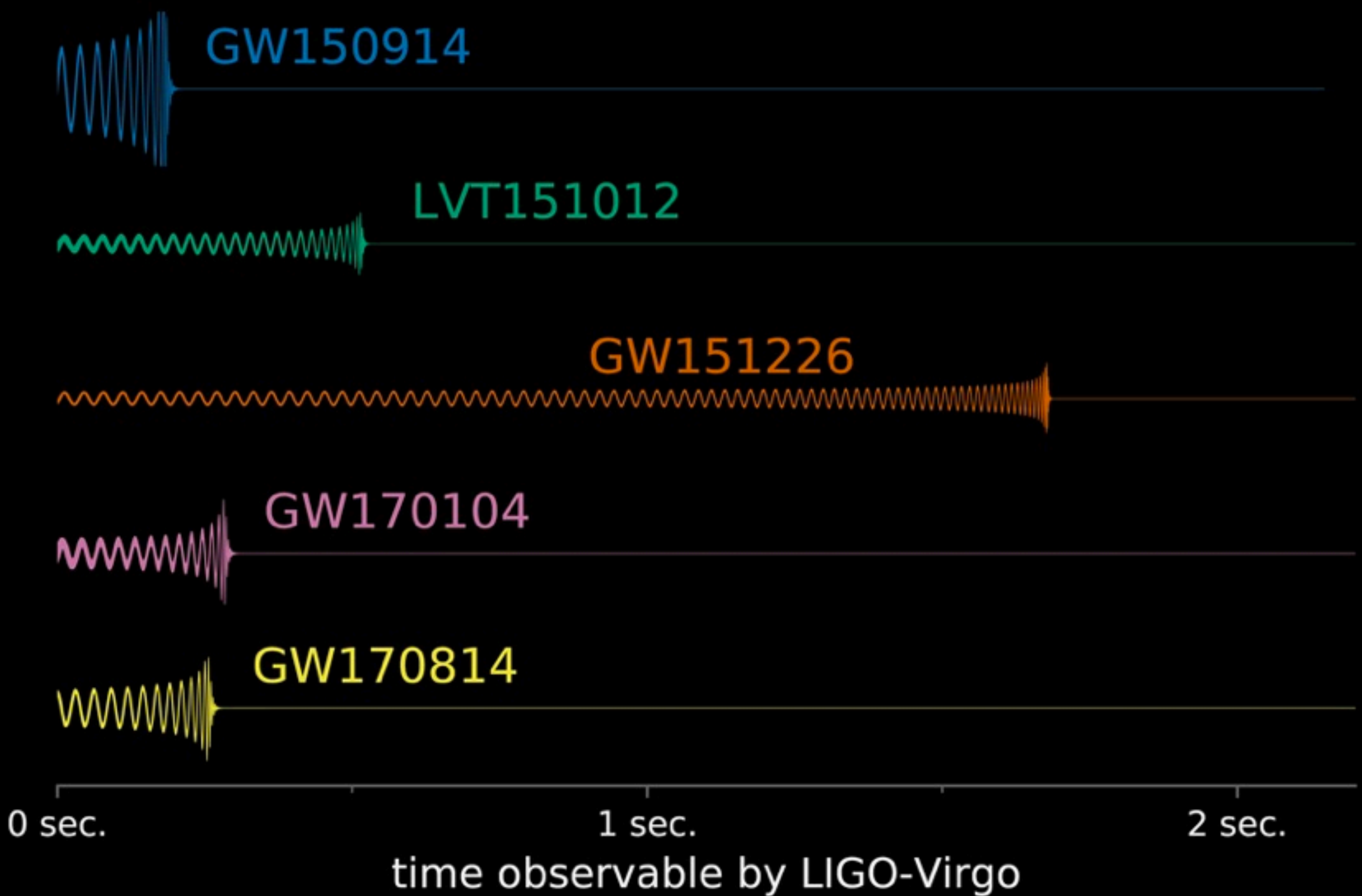
$$\langle s|h\rangle = 4\mathrm{Re}\int_0^\infty \frac{\tilde{s}(f)\tilde{h}^*(f)}{S_n(f)} e^{2\pi i f t} df$$





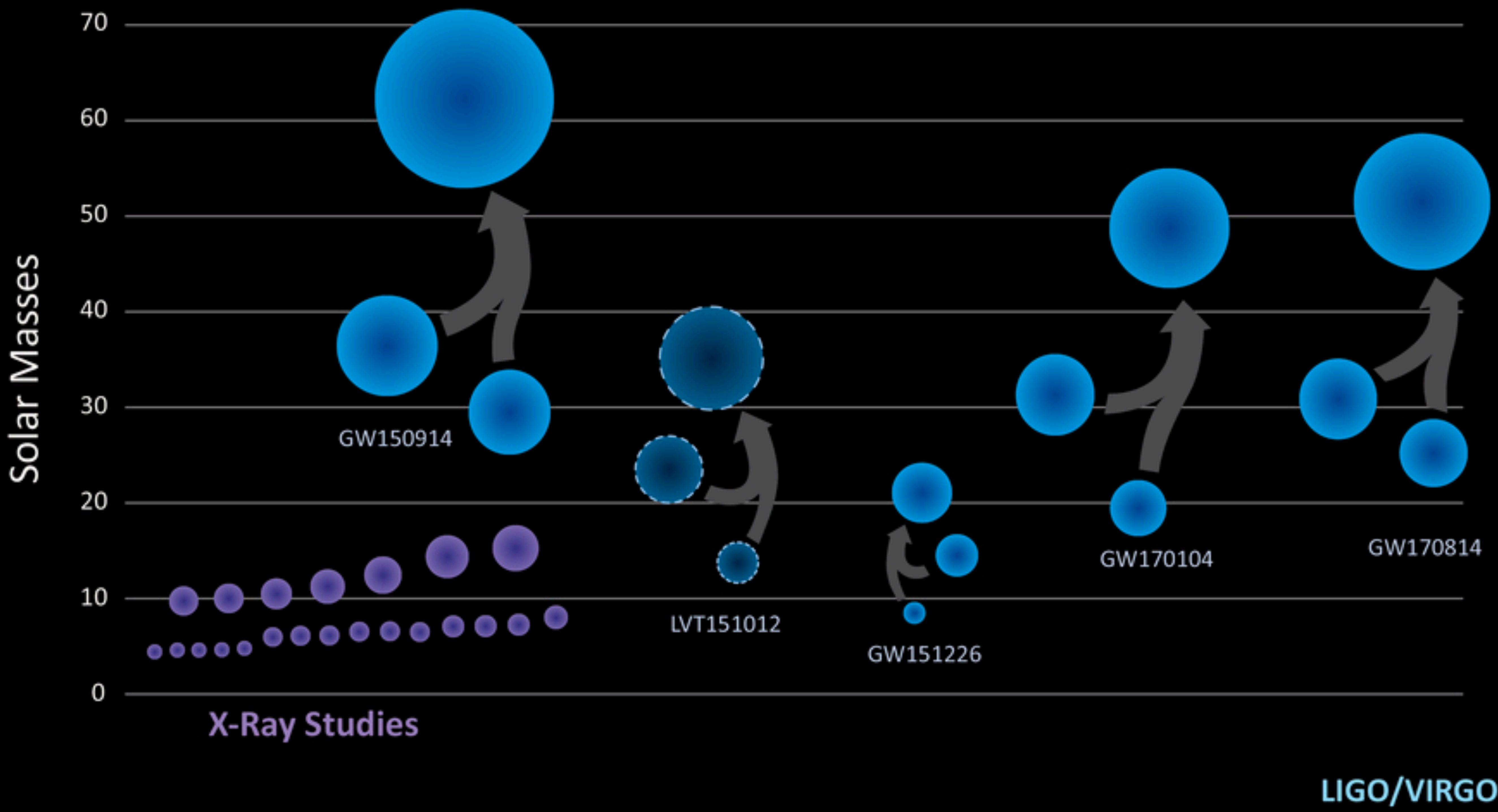
B. P. Abbott et al. Phys. Rev. X (2016)

Observed black hole mergers to date



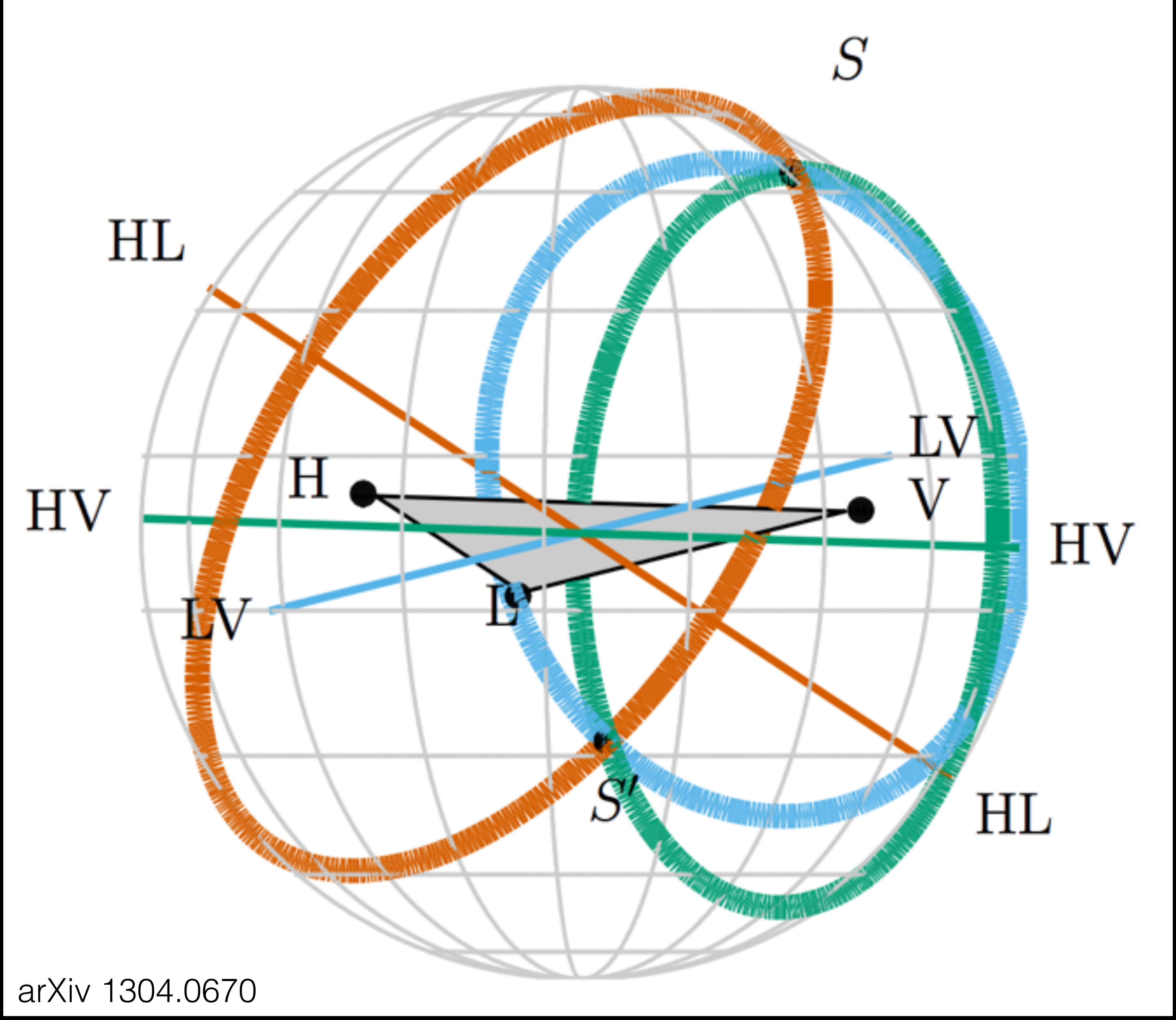
LIGO/Caltech/MIT/LSC

Black Holes of Known Mass



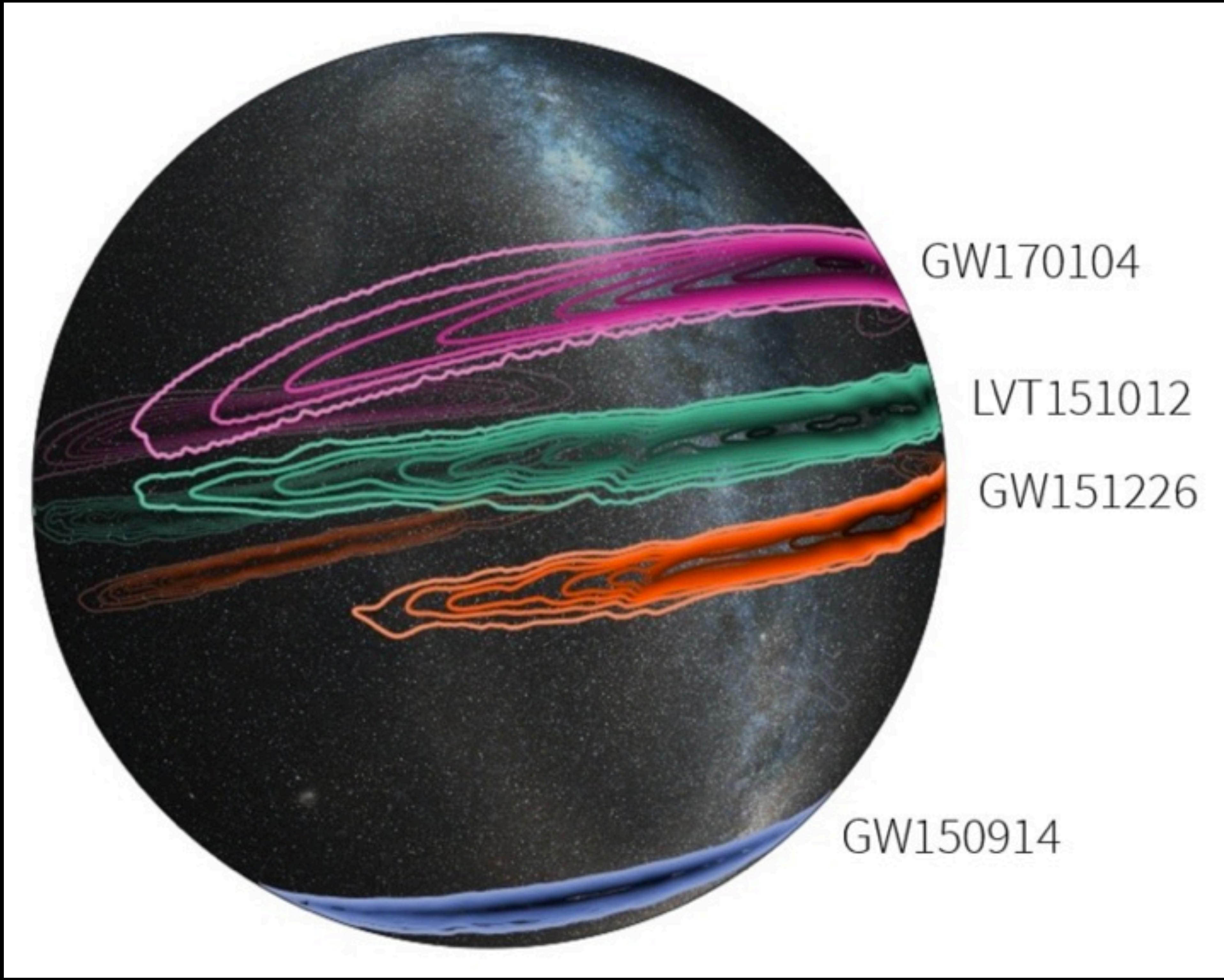
LIGO/Caltech

Sky localization



arXiv 1304.0670

Sky localization of BBHs with LIGO

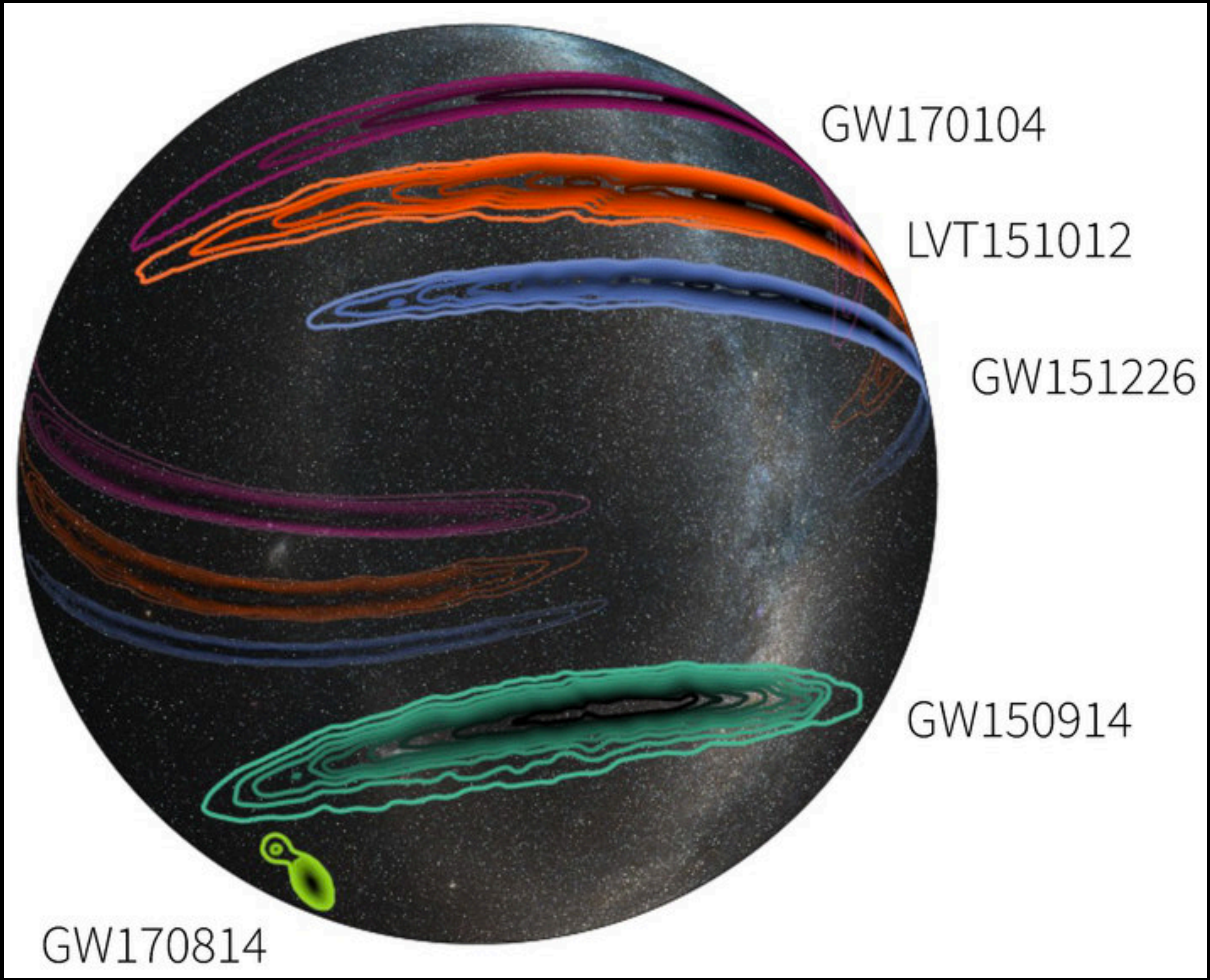


LIGO/Caltech/MIT/Singer/Mellinger

A three interferometer network
and EM observer partners

LIGO/Caltech

Sky localization with three detectors



LIGO/Caltech/MIT/Singer/Mellinger

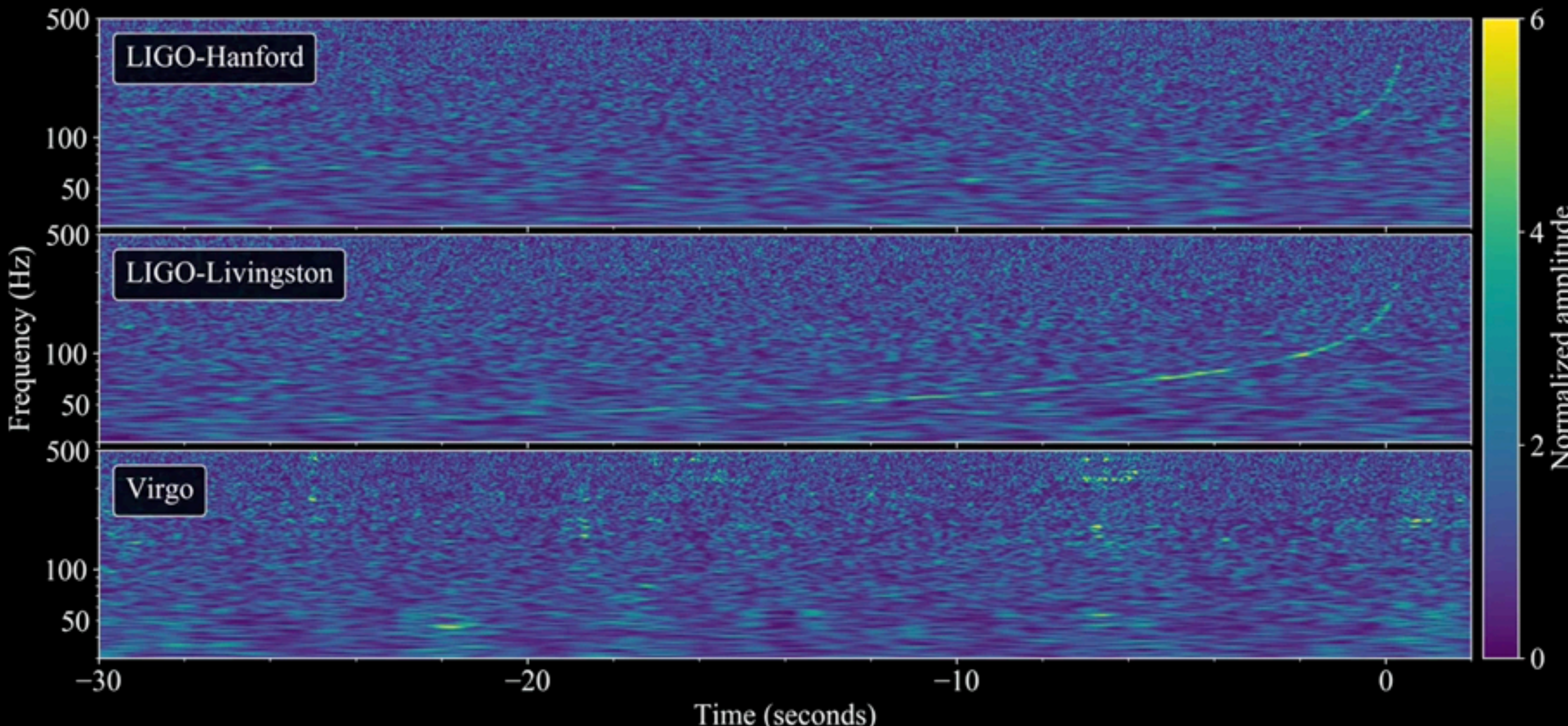
Prior to the Advanced LIGO's second observing run (O2), no BNS mergers were observed.

The first observing run (O1) placed upper limits on the rate of BNS mergers that did not yet rule out any astrophysical predictions (as high as ~ 10,000 Gpc^{-3} yr^{-1})

130 million years ago, two neutron stars merged

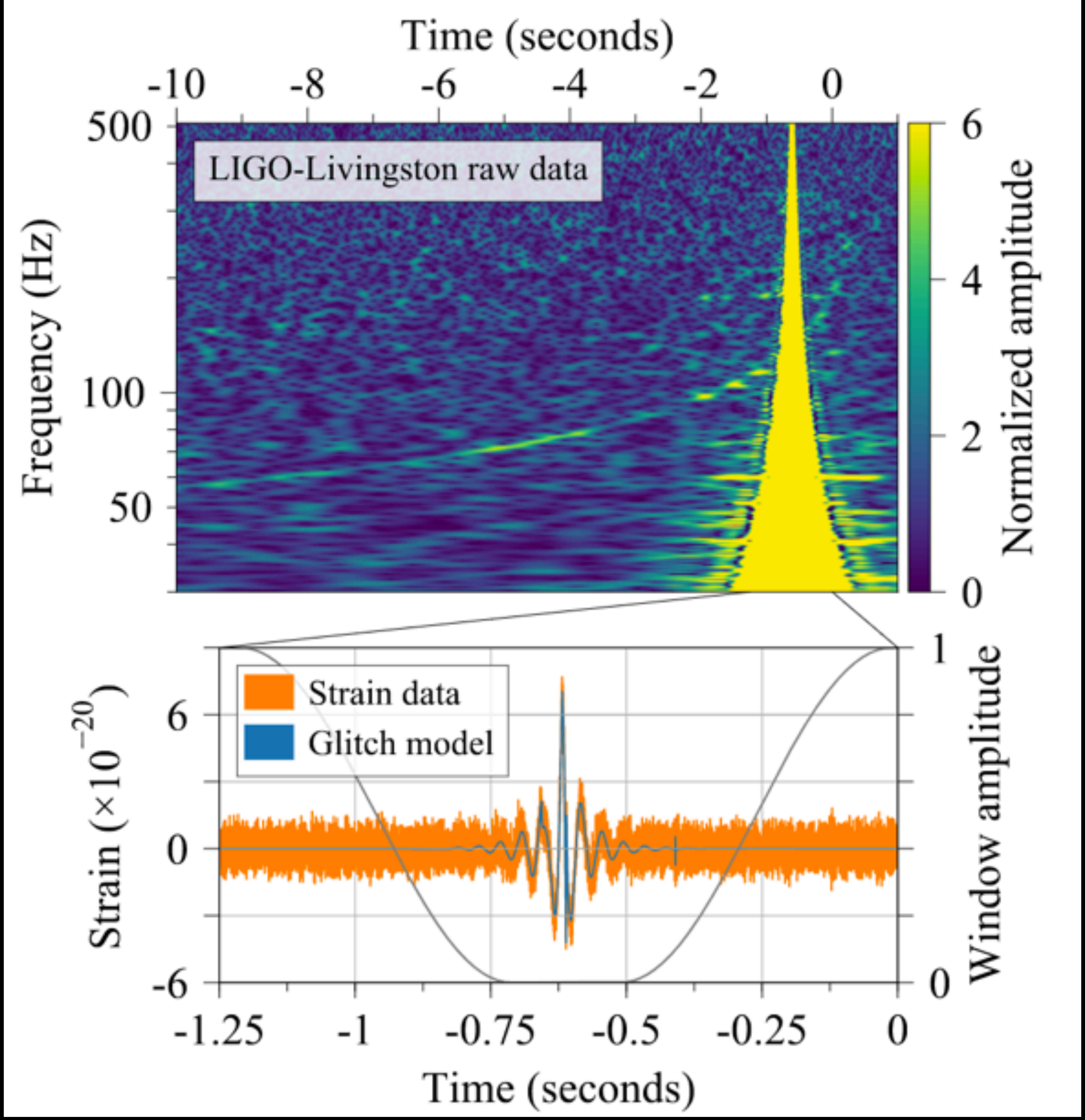
NASA/Goddard Space Flight Center/CI Lab

GW170817: Gravitational waves from a binary neutron star merger



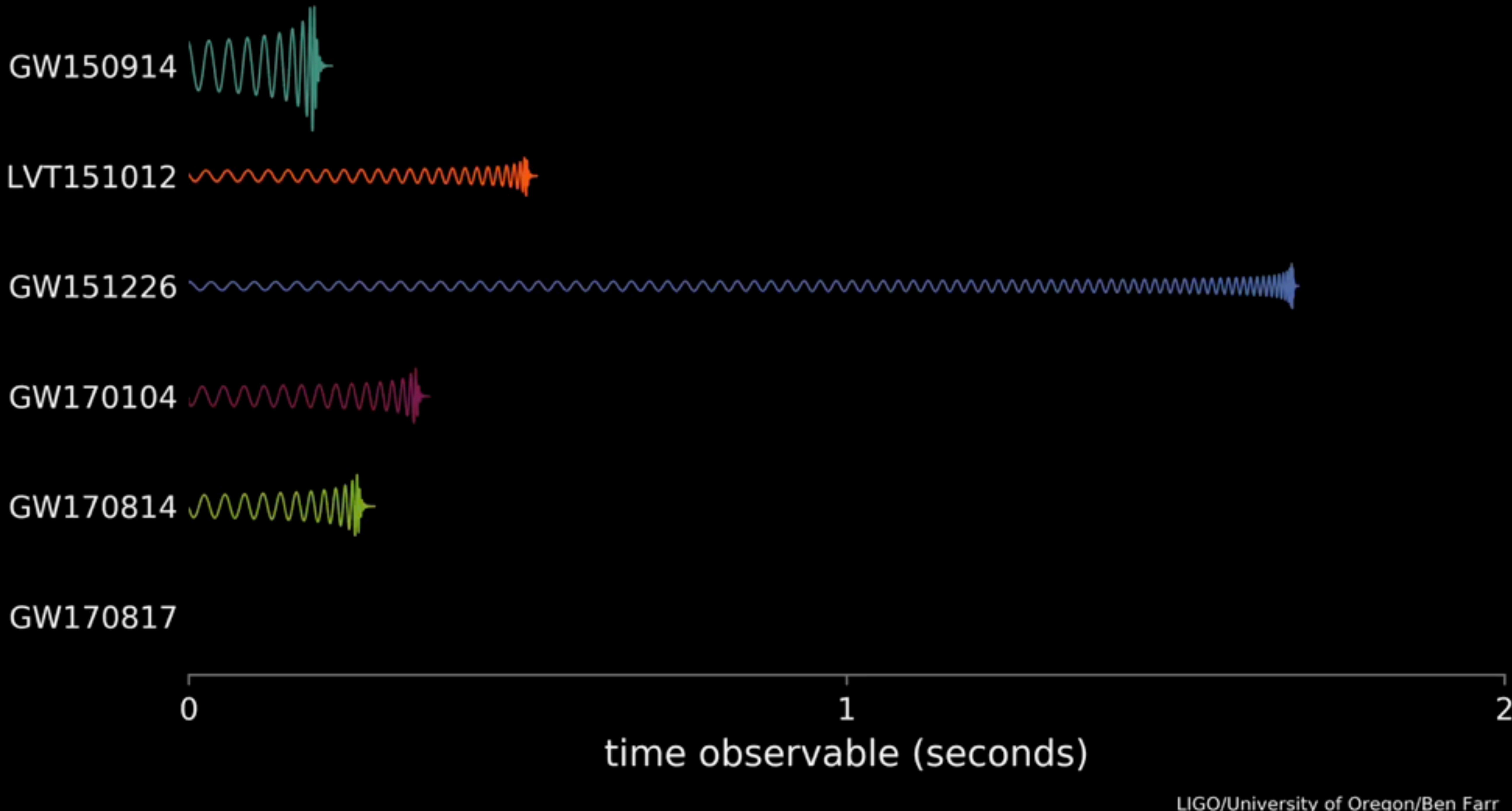
LIGO/Virgo/Lovelace, Brown, Macleod, McIver, Nitz

A glitch in LIGO-Livingston



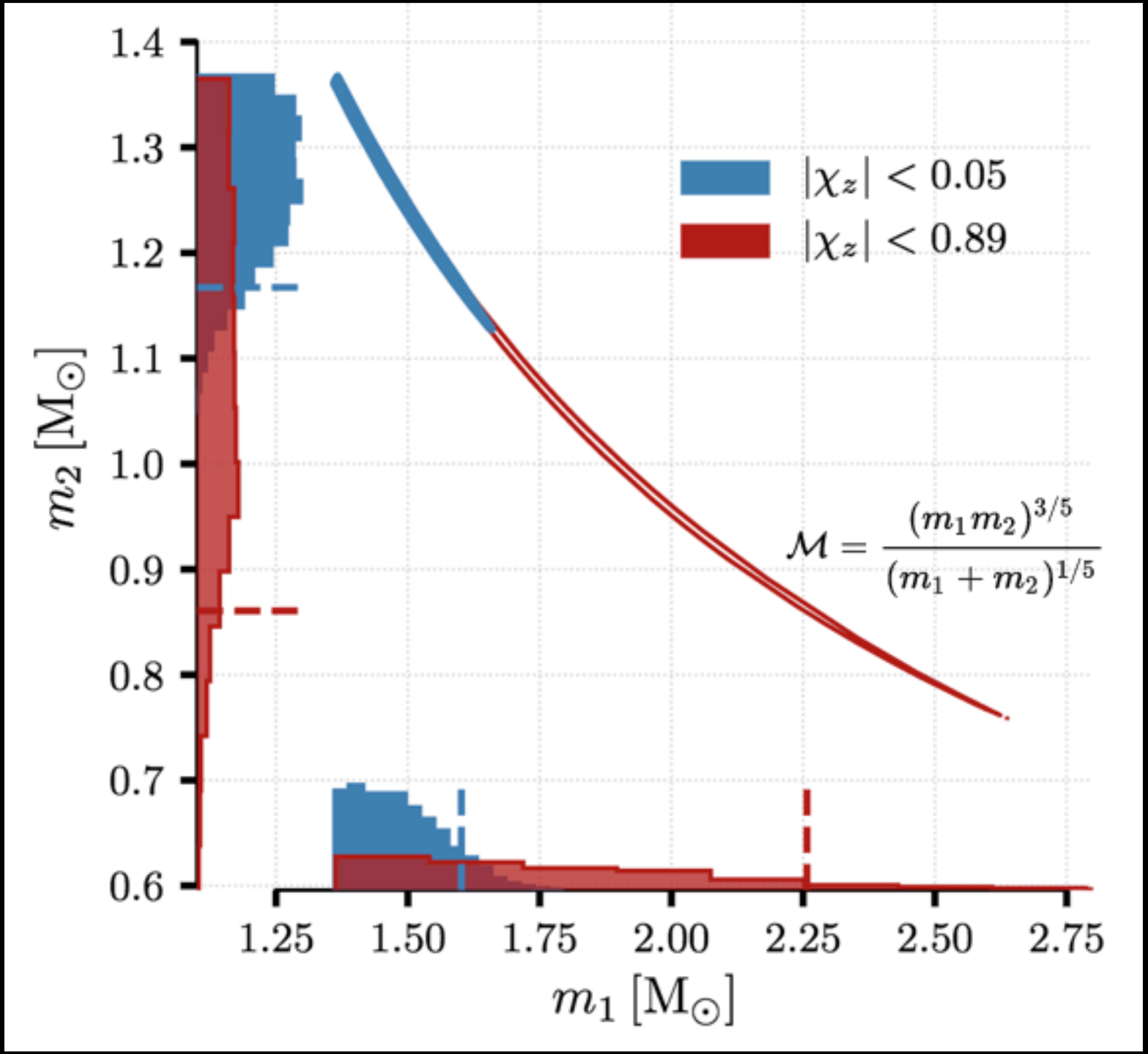
B.P. Abbott et al PRL. (2017)

GW170817 and GWs from binary black holes

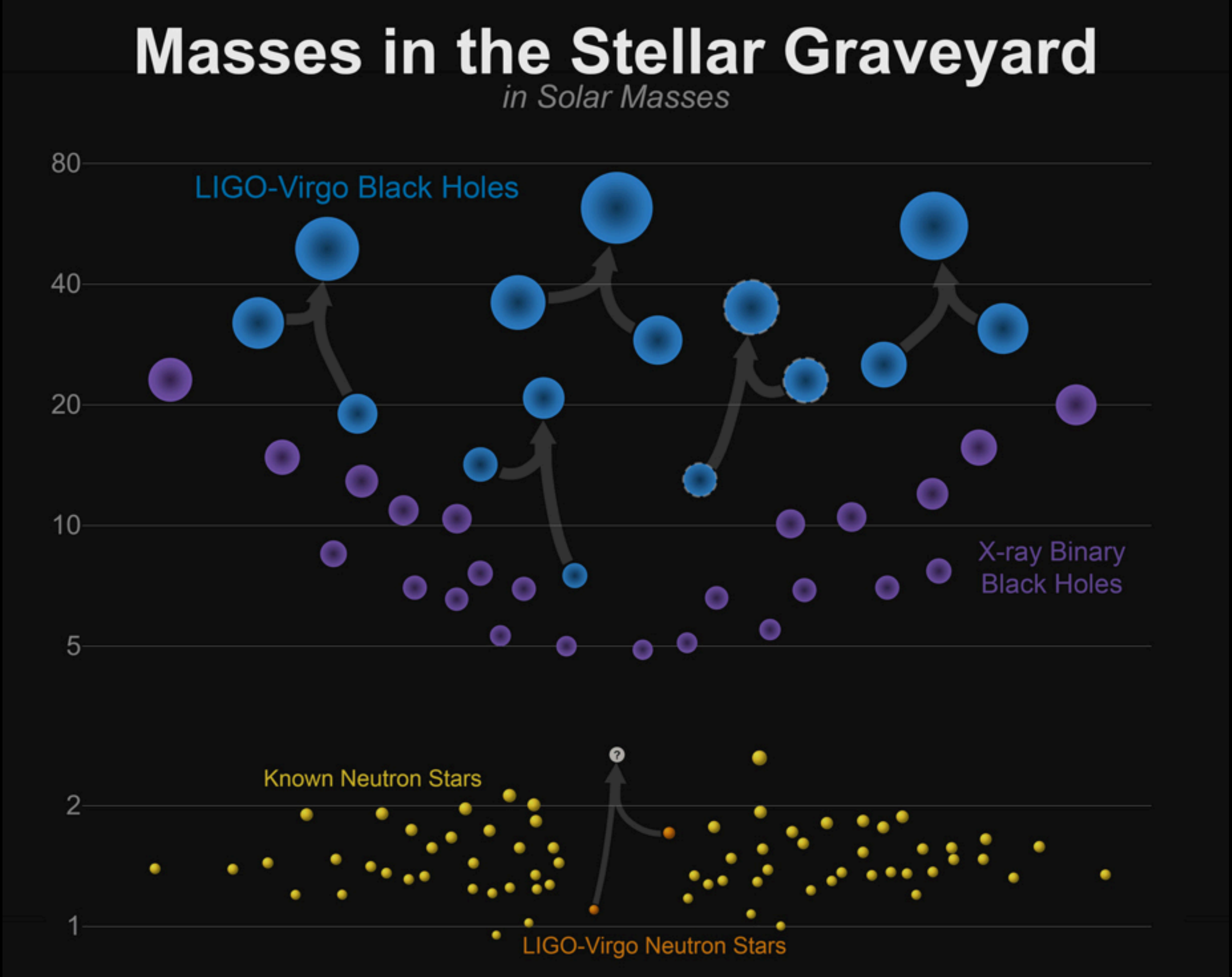


LIGO/University of Oregon/Ben Farr

From GWs: inferring the component masses



B.P. Abbott et al PRL. (2017)

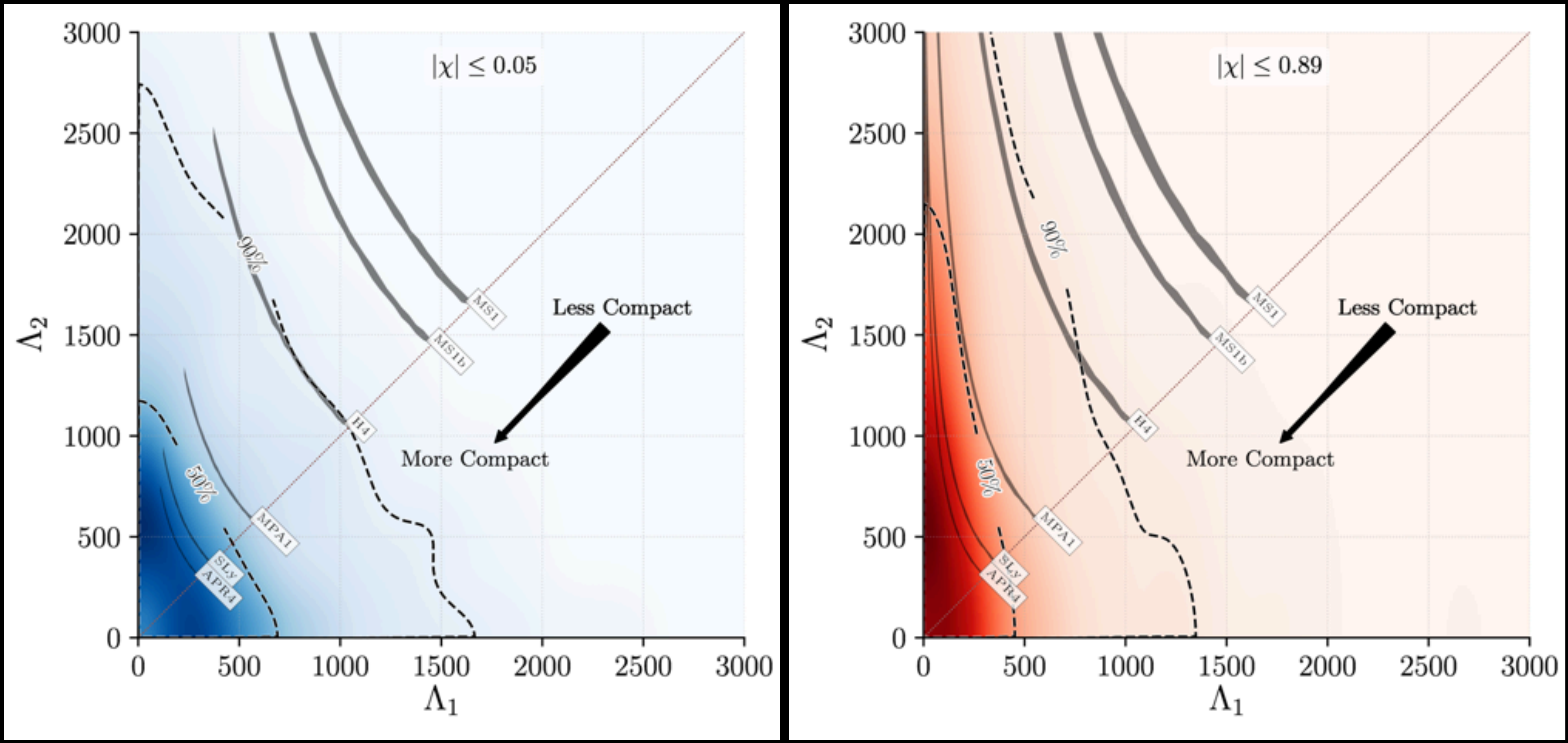


LIGO-Virgo/Frank Elavsky/Northwestern University

From GWs: constraining NS EoS

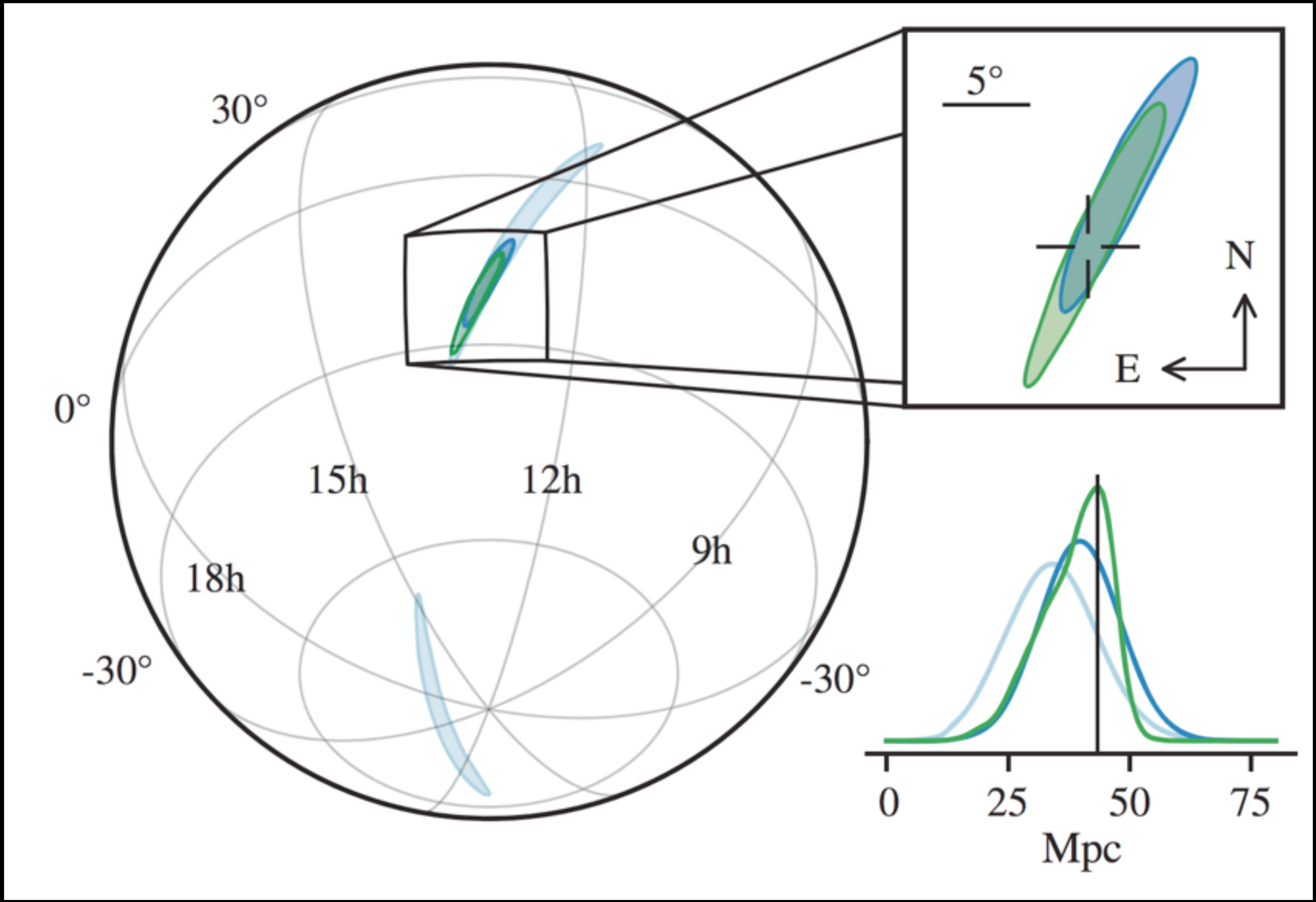
Tidal deformability

$$\Lambda = (2/3)k_2[(c^2/G)(R/m)]^5$$



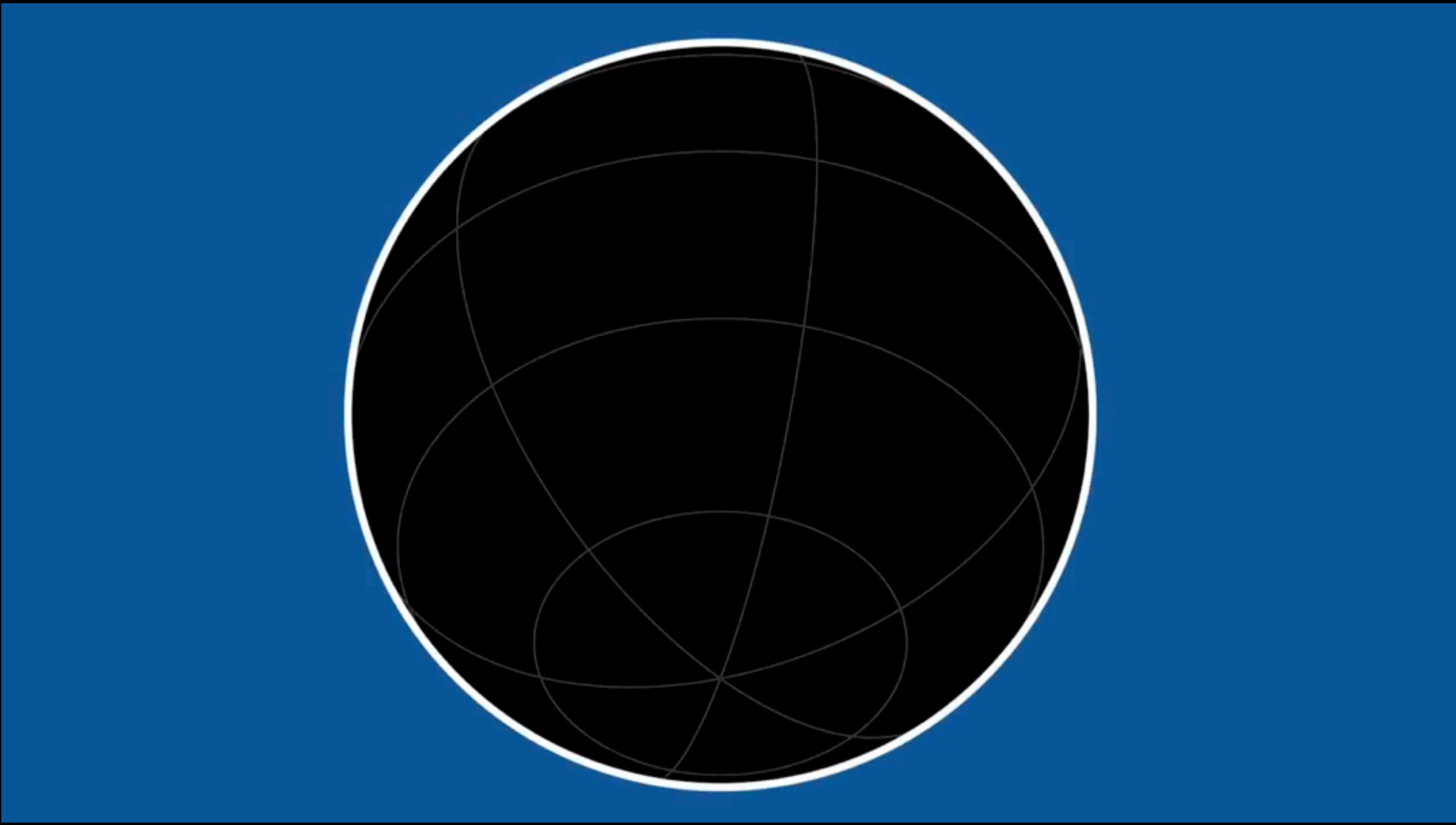
B.P. Abbott et al PRL. (2017)

From GWs: sky localization

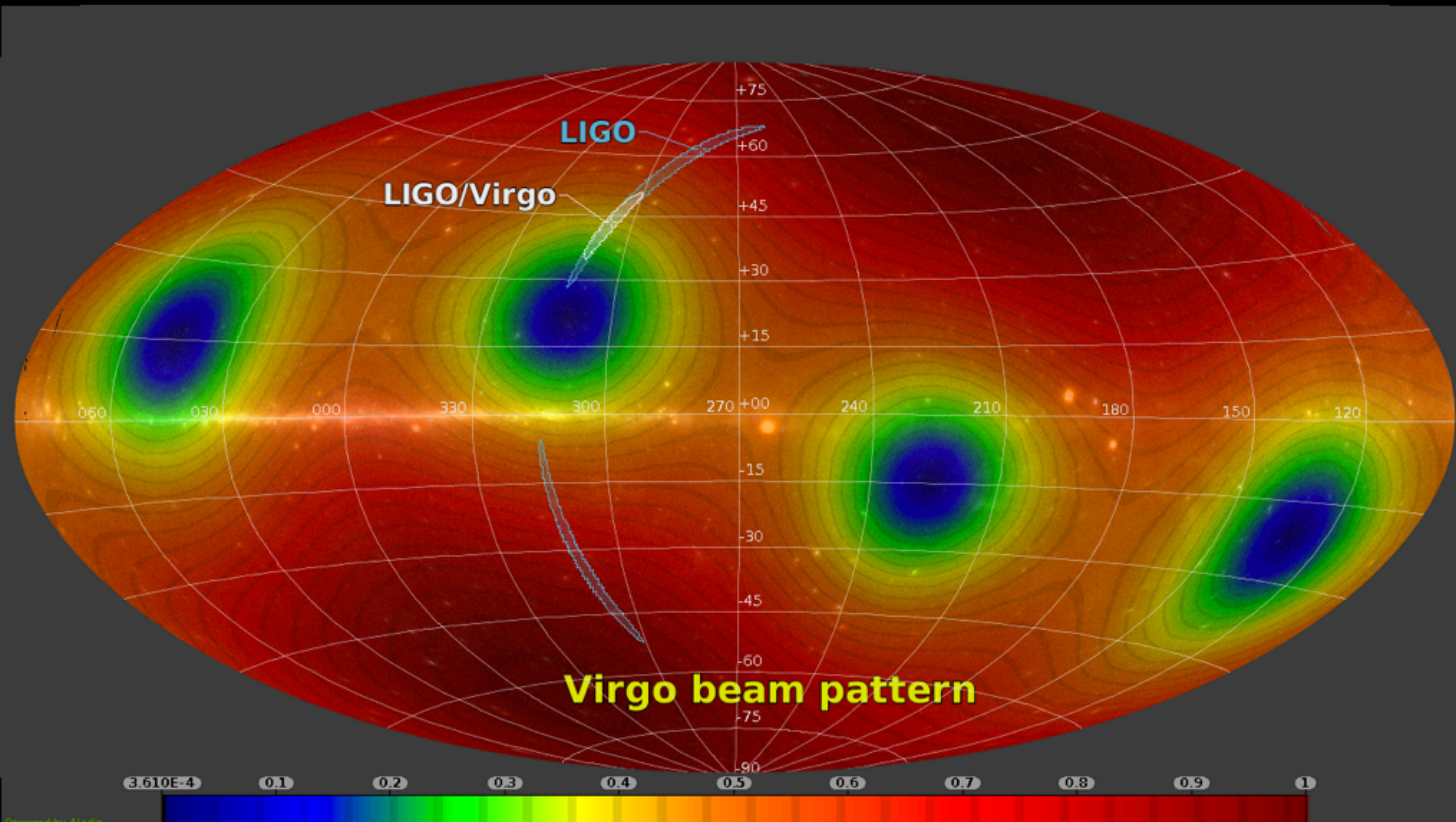


B.P. Abbott et al. PRL (2017)

Sky localization with GWs and gamma rays

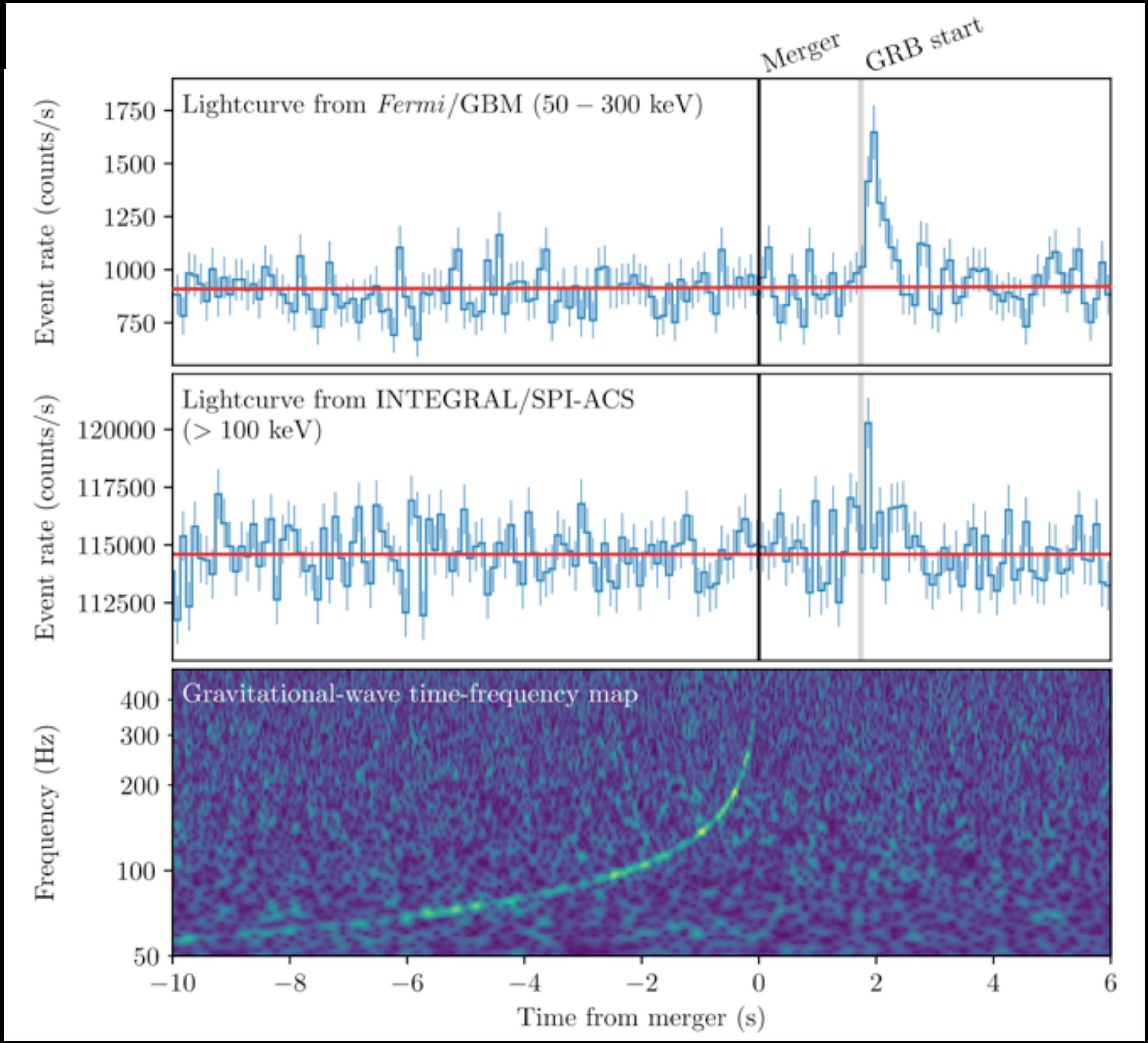


Virgo's role in localization



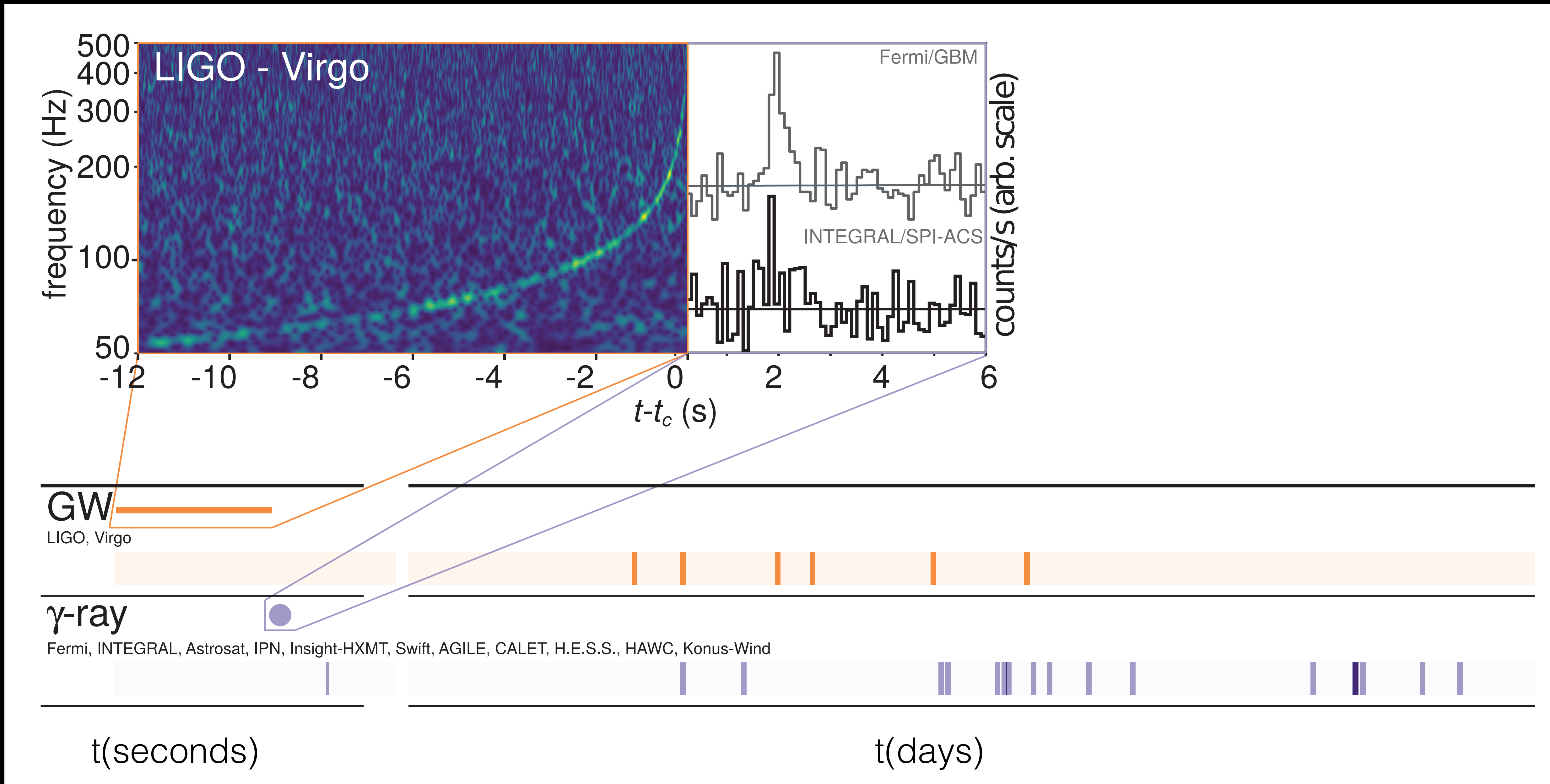
LIGO-Virgo/Greco, Arnaud, Vicerè

Prompt emission: GWs and gamma rays



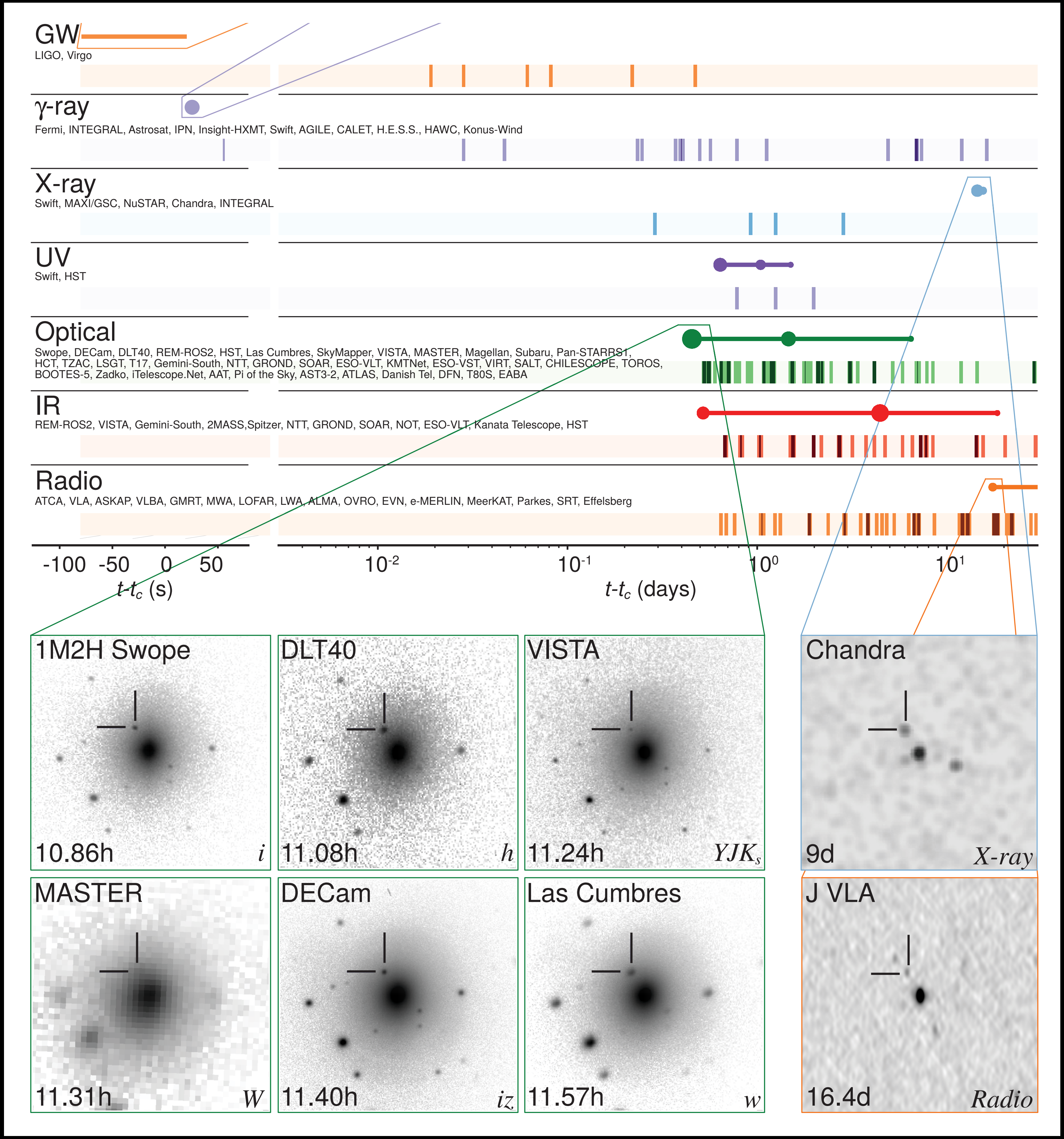
B.P. Abbott et al. Ap. J. Letters (2017)

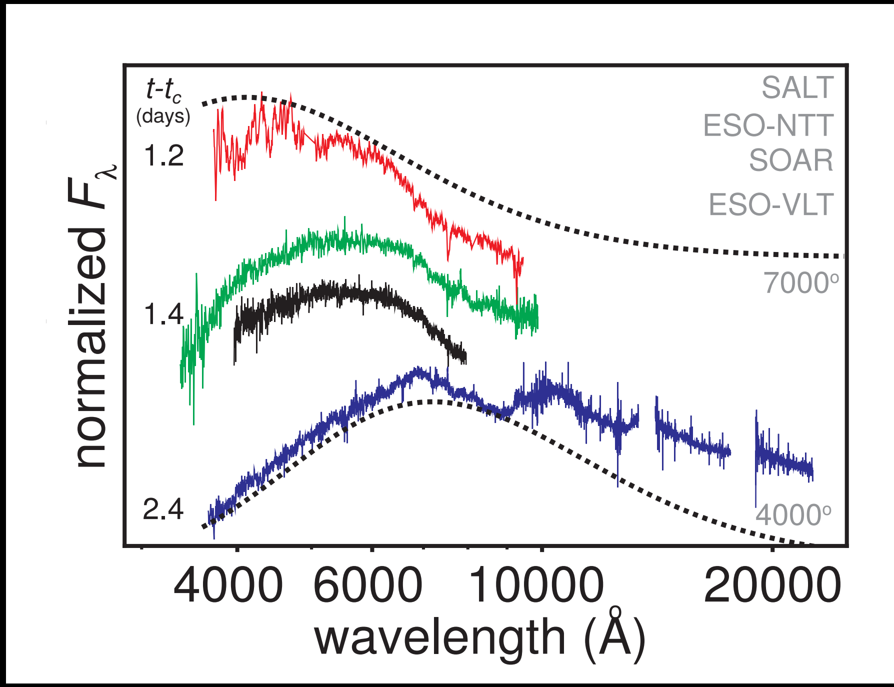
Prompt emission: GWs and gamma rays



B.P. Abbott et al. Ap. J. Letters (2017)

Electromagnetic follow-up





B.P. Abbott et al. Ap. J. Letters (2017)

What we've learned from GW170817

From gravitational waves:

- Astrophysical rate of BNS mergers $R = 1540^{+3200}_{-1220}$ $\text{Gpc}^{-3}\ \text{yr}^{-1}$
- *Stochastic background from BNS and BBH mergers should be detectable with current generation of detectors at design sensitivity!*
- Limits on dynamical ejecta in the associated kilonova.
- To come: improved constraints on deviations from general relativity using much longer duration waveform.
- To come: insight on the remnant object from the post-merger GW signal.

Companion papers:

1. *GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral.* B.P. Abbott et al. PRL 119 161101 (2017)
2. *GW170817: Implications for the Stochastic Gravitational-Wave* Background from Compact Binary Coalescences. arXiv 1710.05837
3. *Estimating the Contribution of Dynamical Ejecta in the Kilonova Associated with GW170817*. arXiv 1710.05836

What we've learned from GW170817

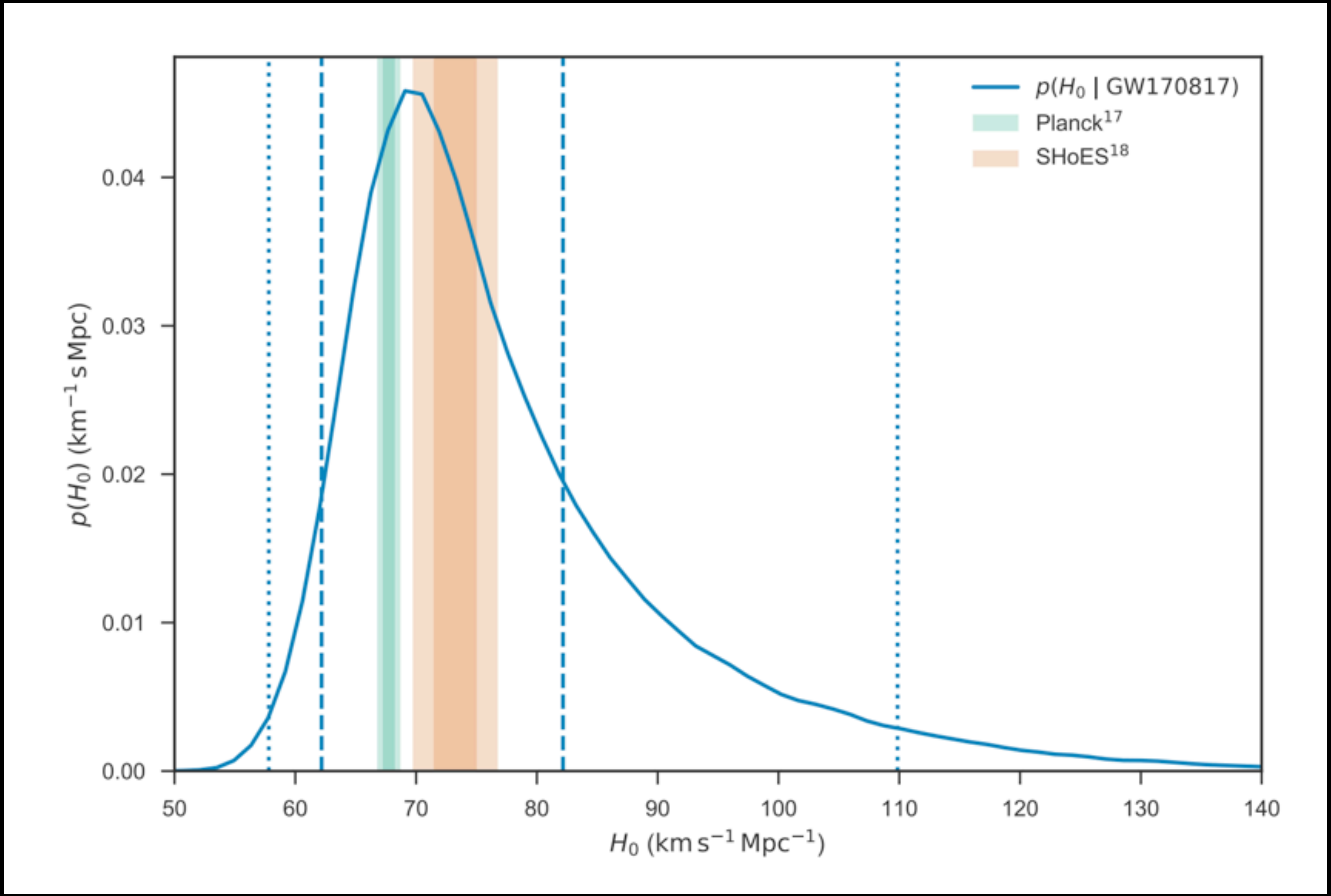
From multi-messenger observations:

- Confirmation of association between short GRBs and BNS mergers.
- Independent measurement of the Hubble constant consistent with prior measurements.
- Speed of gravity is consistent with speed of light to one part in 10^{15}.
- Improved Lorentz invariance limits; constrained to one part in 10^{13}.
- New insights into physics of gamma-ray burst events.
- Constraints on progenitors and the evolution of the BNS pair.
- BNS mergers as producers of heavy elements confirmed.
- More to come - see Kasliwal/Hallinan CaJAGWR seminar on Nov 7!

Companion papers:

1. *Multi-Messenger Observations of a Binary Neutron Star Merger.* B.P. Abbott et al. Ap. J. Letters 848, 2 (2017)
2. *Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A*. B.P. Abbott et al. Ap. J. Letters 848, 2 (2017)
3. *A gravitational-wave standard siren measurement of the Hubble constant*. B.P. Abbott et al. Nature (2017)
4. *On the Progenitor of Binary Neutron Star Merger GW170817. arXiv 1710.05838*
5. *Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory. arXiv 1710.05839*

Independent measurement of the Hubble constant

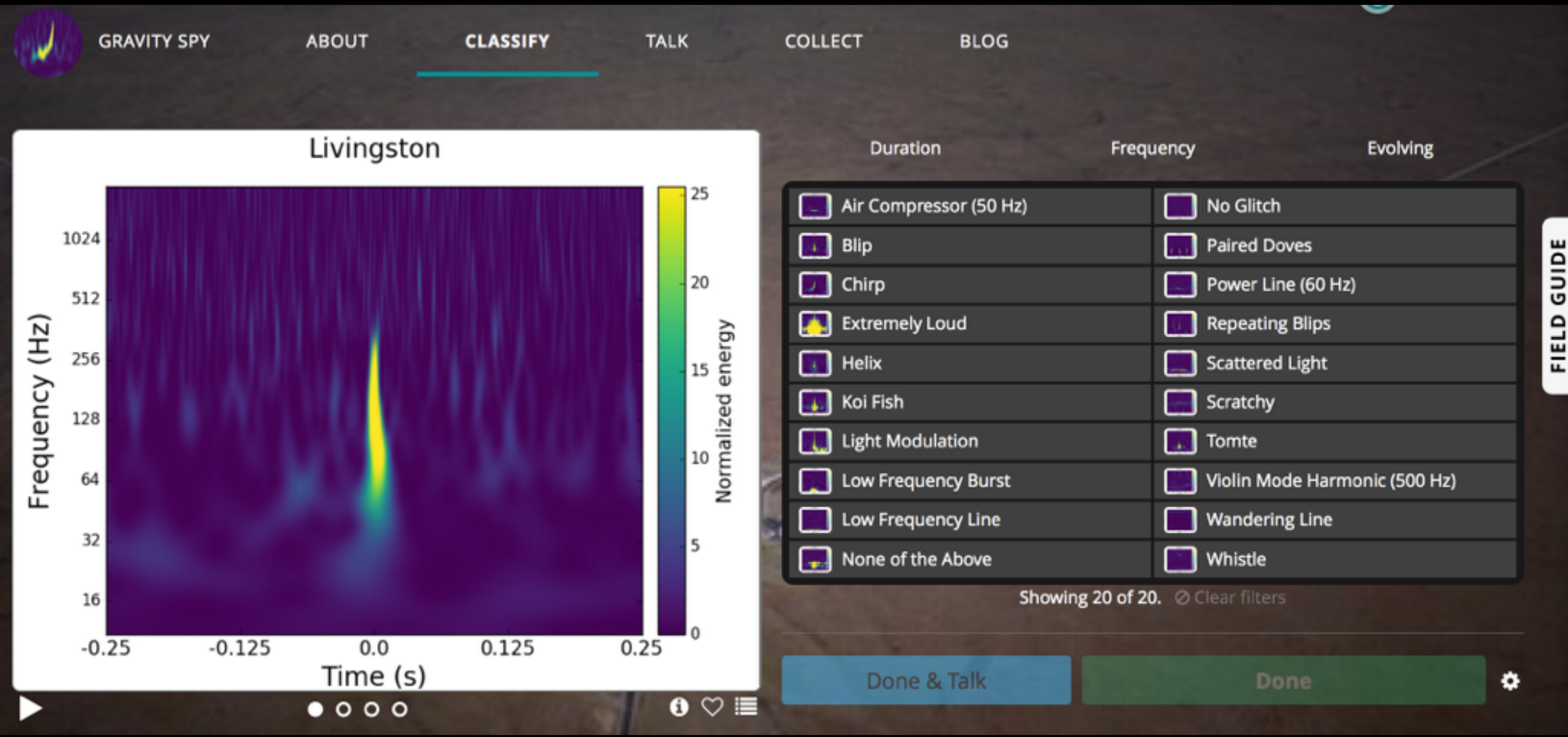


B.P. Abbott et al. Nature (2017)

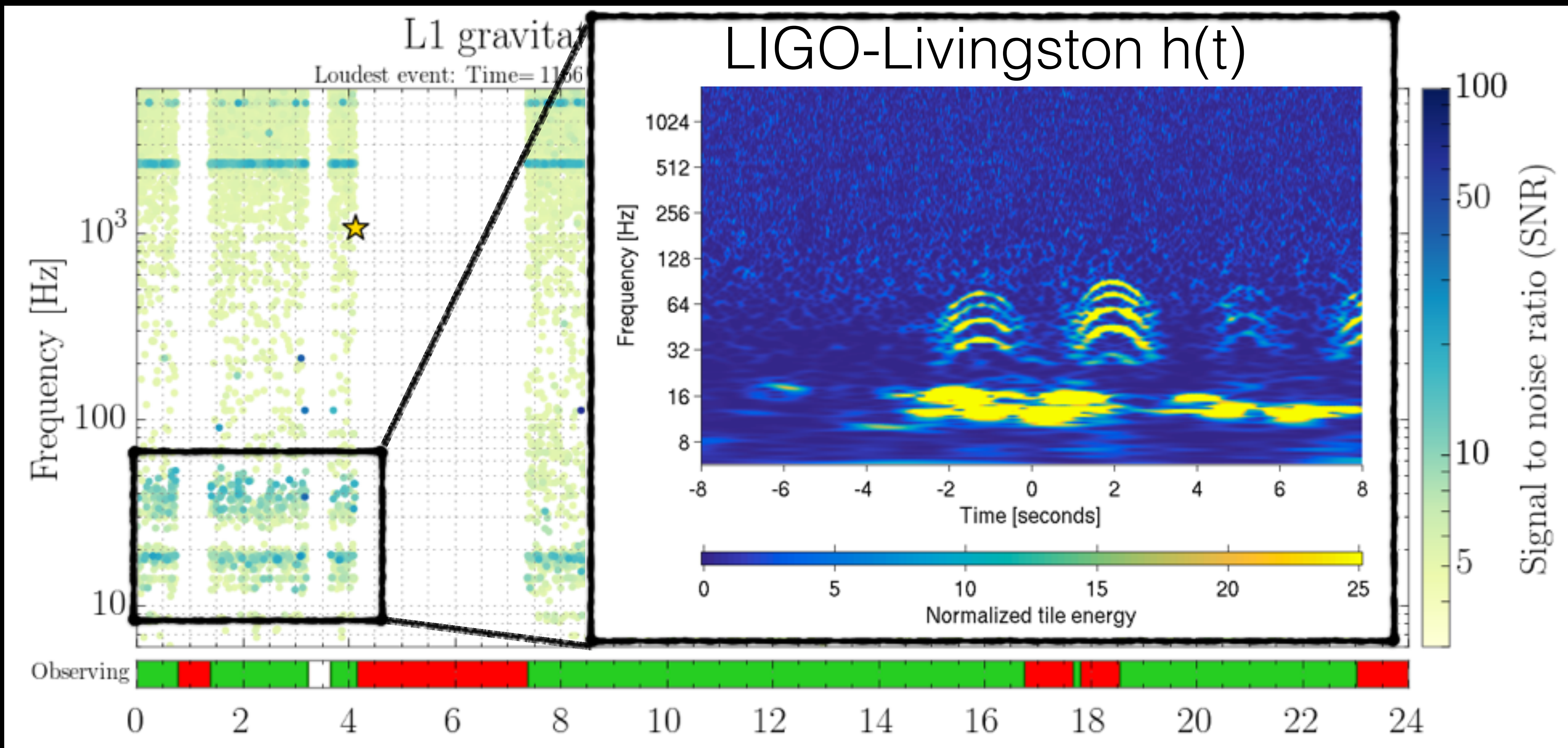
Future challenges: targeting transient noise

gravityspy.org

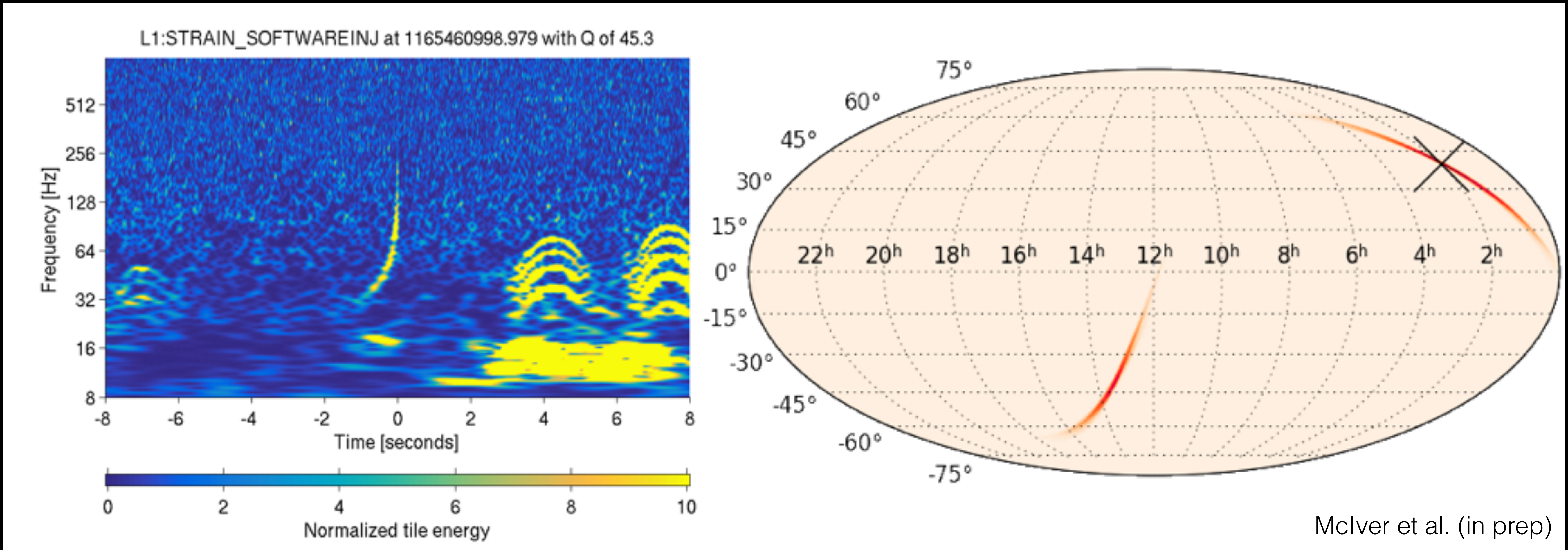
Zevin et al, CQG (2017)



LIGO-Livingston transient noise during the second observing run



Understanding the impact of transient noise on estimation of source properties

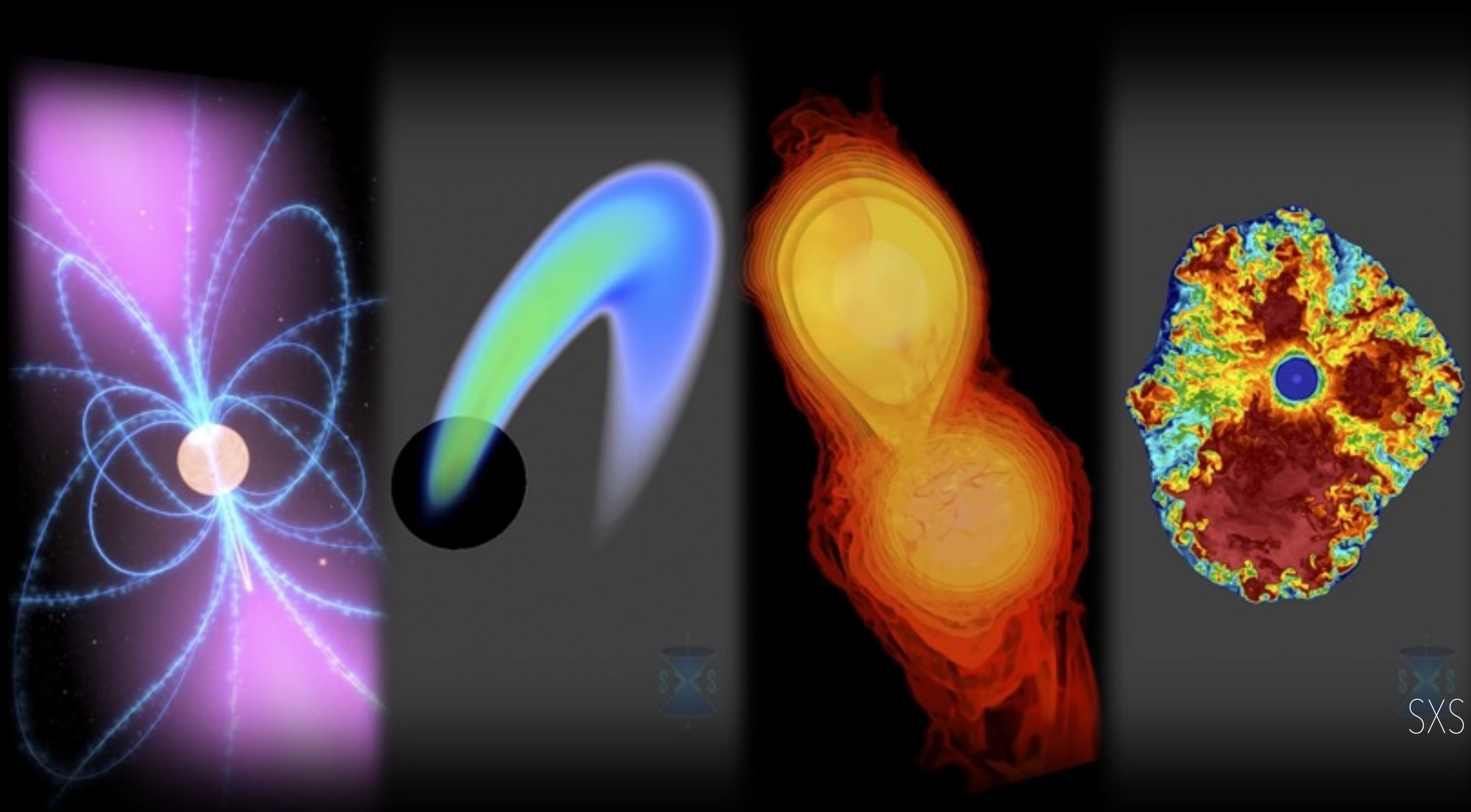


McIver et al. (in prep)

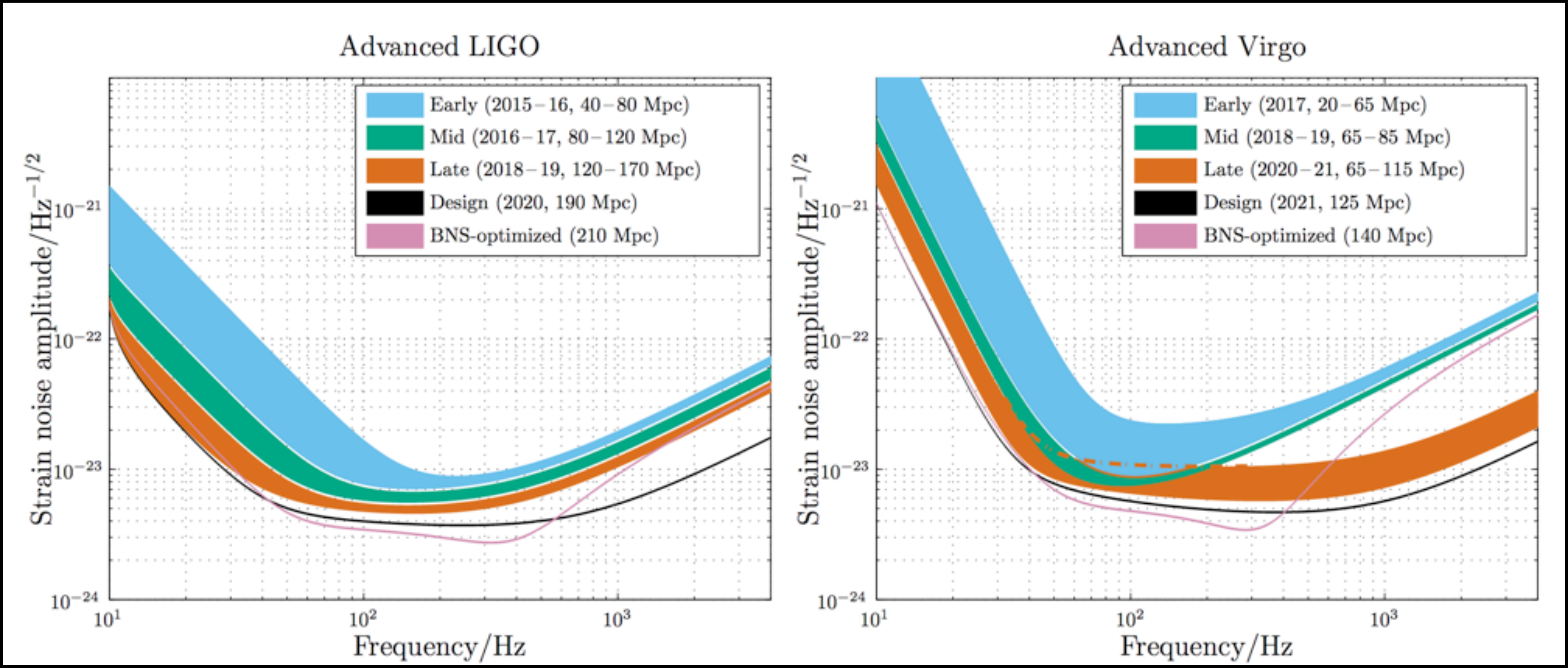
Parameter estimation produced with the lalinference pipeline: arXiv 1409.7215

Minimum 90% confidence sky area (2 seconds before the scattering noise feature): 300 sq. deg.
Maximum 90% confidence sky area: (During the first 0.5 seconds of the scattering noise): 540 sq. deg.

The future of gravitational wave astronomy

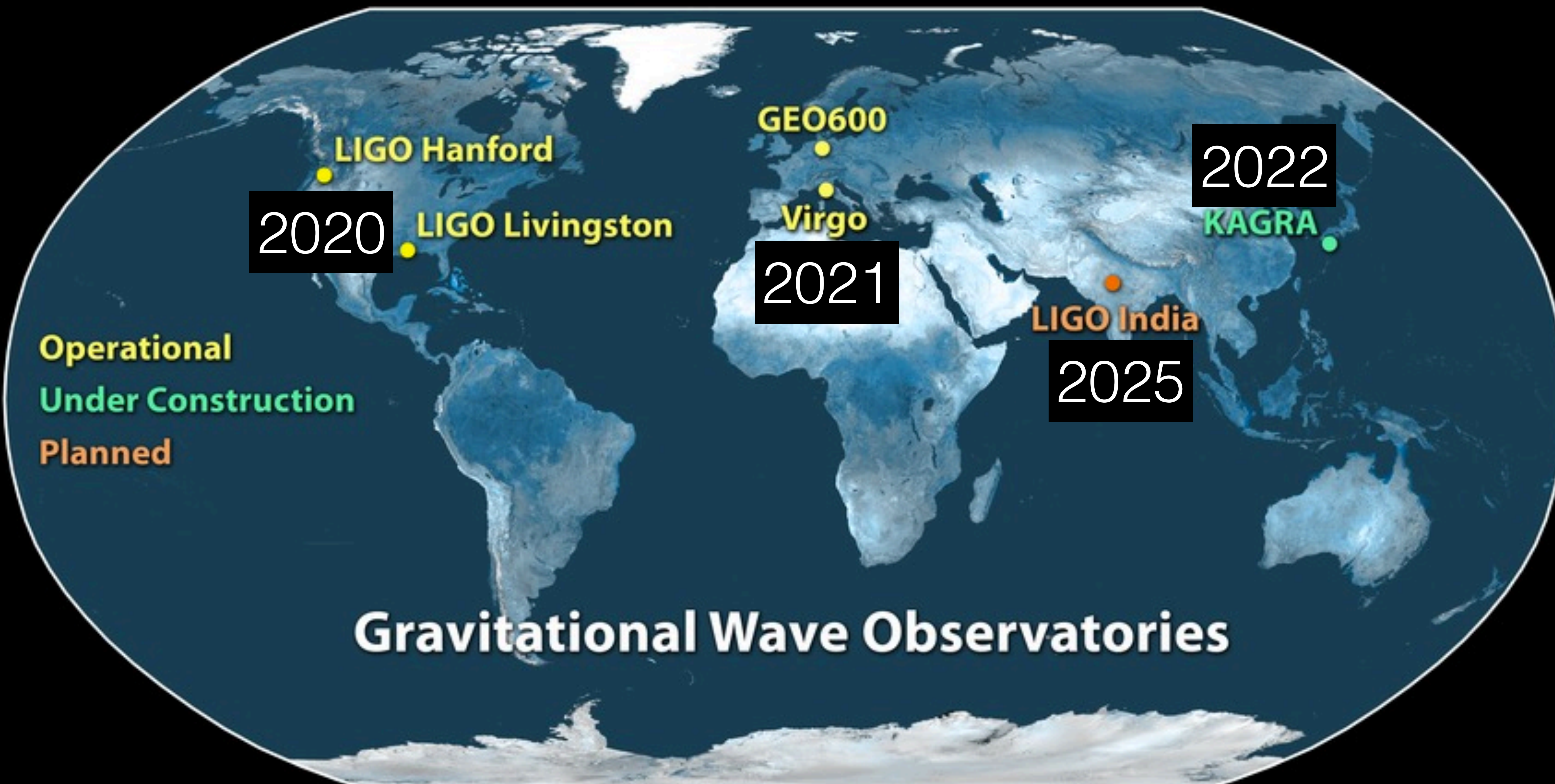


Roadmap to design sensitivity



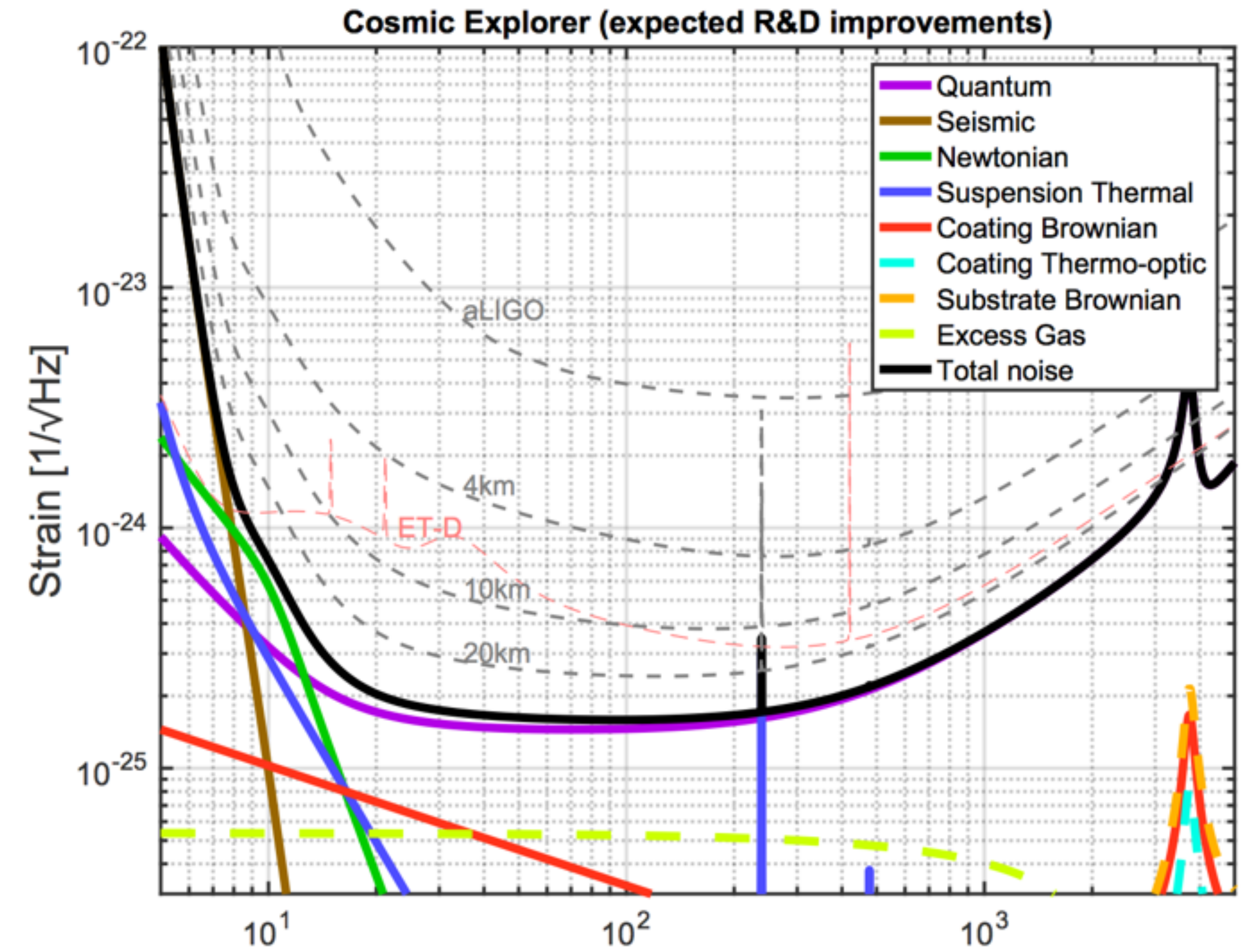
arXiv 1304.0670

Future prospects: the global GW network



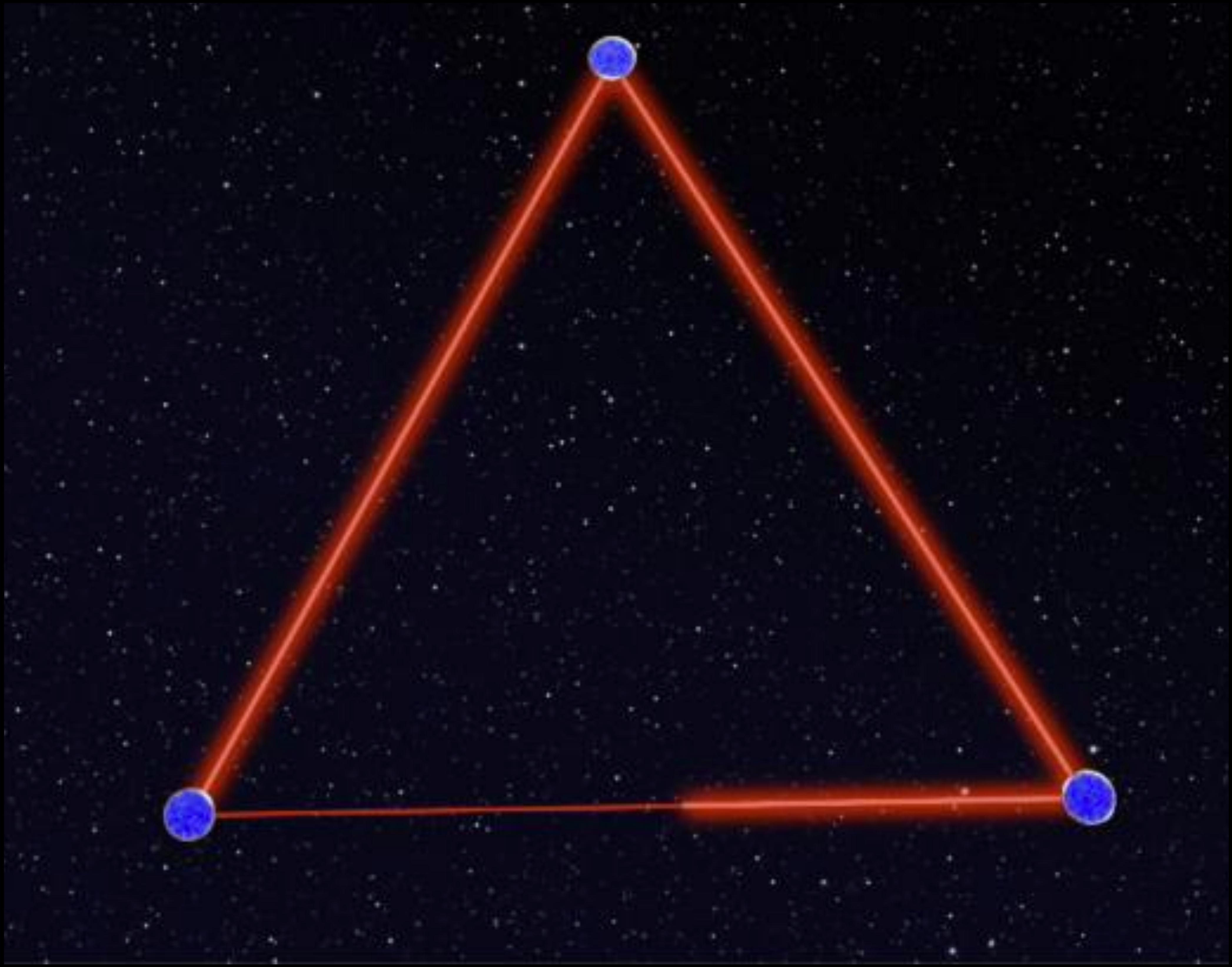
LIGO/Caltech

Future prospects for terrestrial gravitational wave astronomy

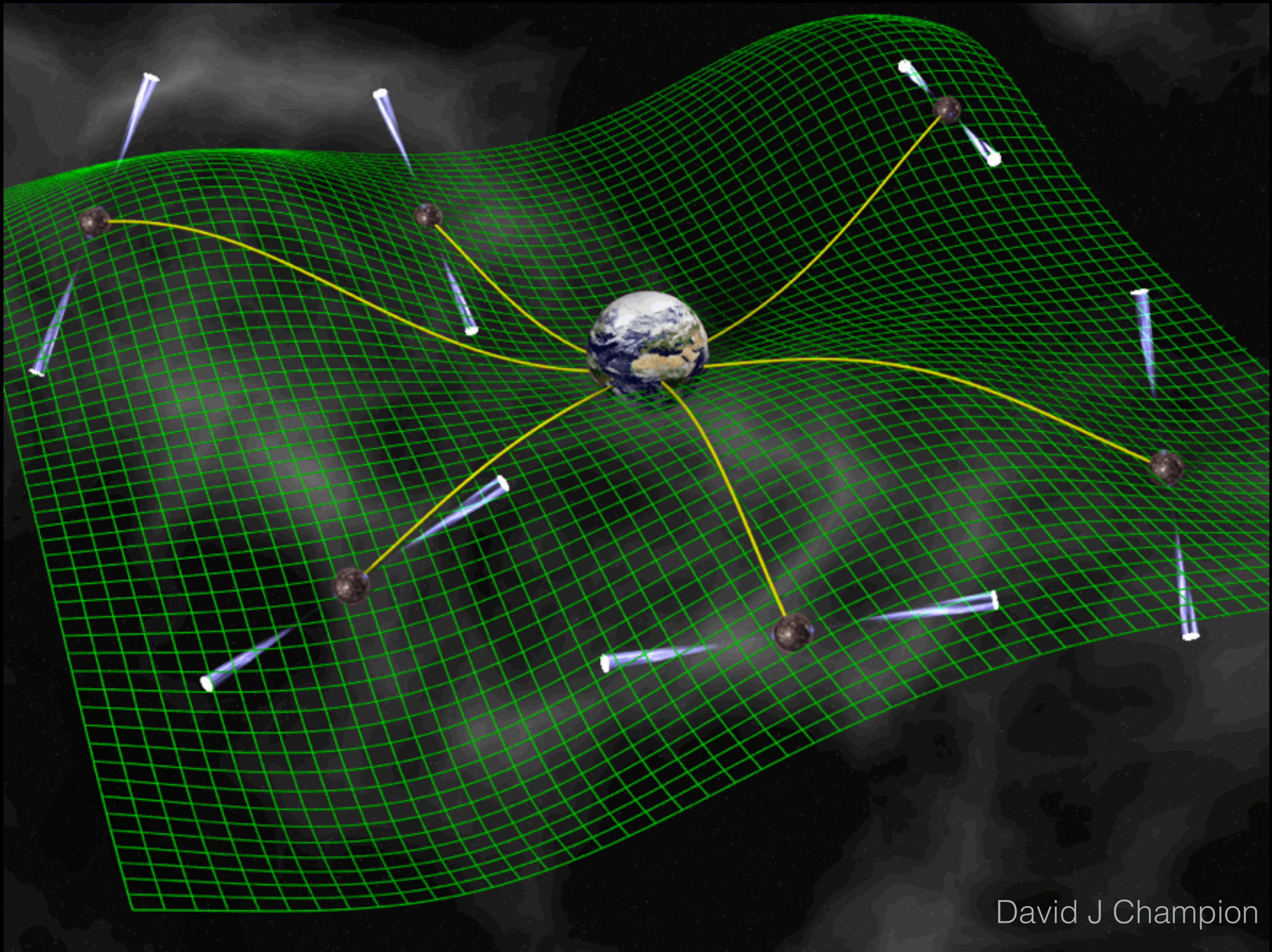


B. P. Abbott et al. CQG 34 (2017)

Beyond terrestrial detectors


ESA

Pulsar Timing Arrays



David J Champion

The International Pulsar Timing Array

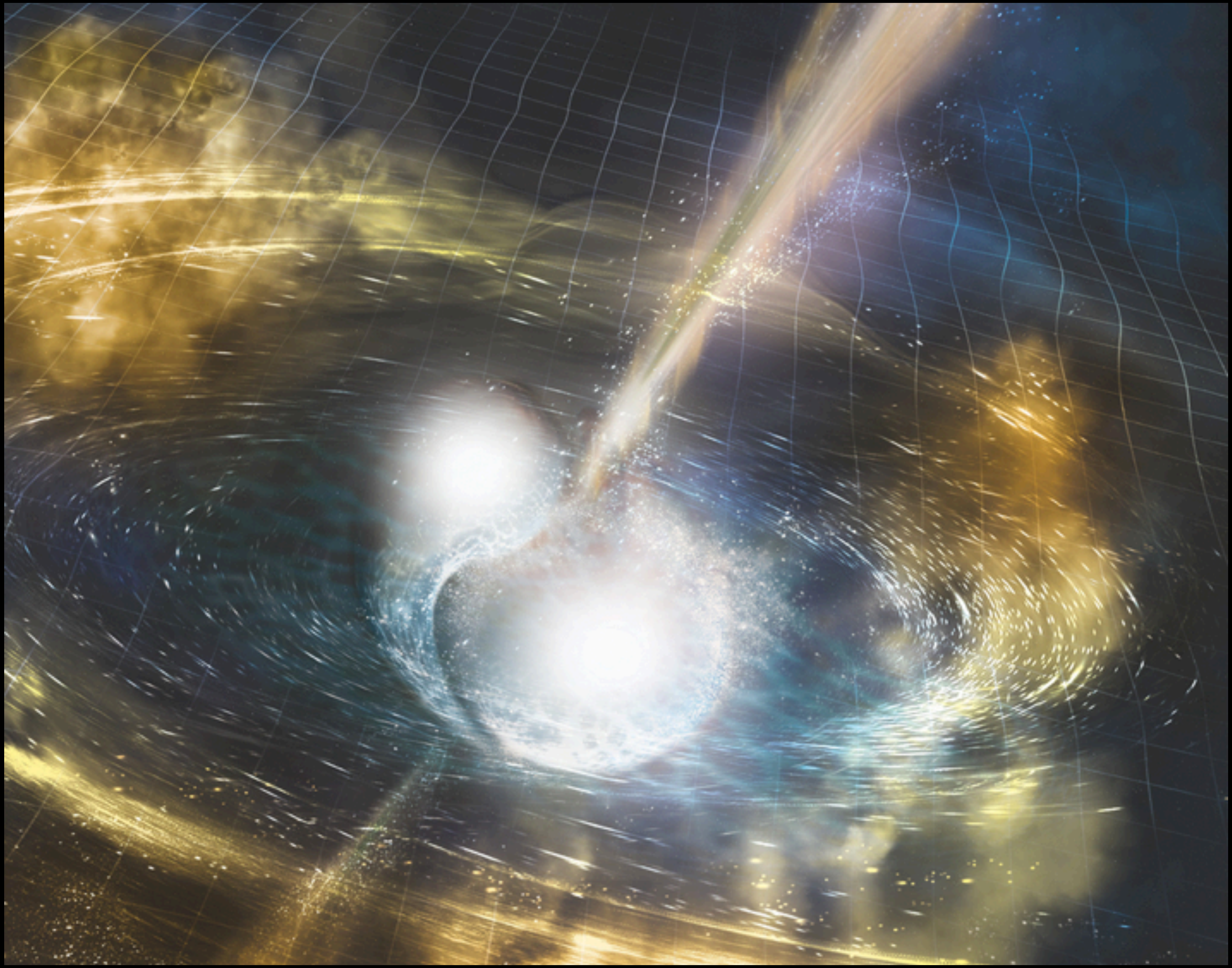
LIGO

LSC

LIGO Scientific Collaboration

- 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
- University of Strathclyde
- Michigan
- Max Planck Institute for Gravitational Physics Albert Einstein Institute
- The University of Western Australia
- PAH
- ACU
- Università degli Studi del Sannio
- CITA ICAT
- Massachusetts Institute of Technology
- NASA Goddard Space Flight Center
- ICTP SAIFR
- University of Cambridge
- Monash University
- Southern University Agricultural & Mechanical College
- The University of Chicago
- Montana State University
- The University of Mississippi
- The University of Adelaide Australia
- Columbia University in the City of New York
- Caltech
- University of Minnesota
- University of Birmingham
- The University of Melbourne
- UIB Universitat de les Illes Balears
- University of Washington
- UTRGV
- UW Milwaukee
- Syracuse University
- Cardiff University Prifysgol Caerdydd
- Northwestern
- Universität Hamburg
- Monash University
- INPE
- UF 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
- William Smith College
- Science & Technology Facilities Council Rutherford Appleton Laboratory

The future of gravitational wave astrophysics is bright!



NSF/LIGO/Sonoma State University/A. Simonnet