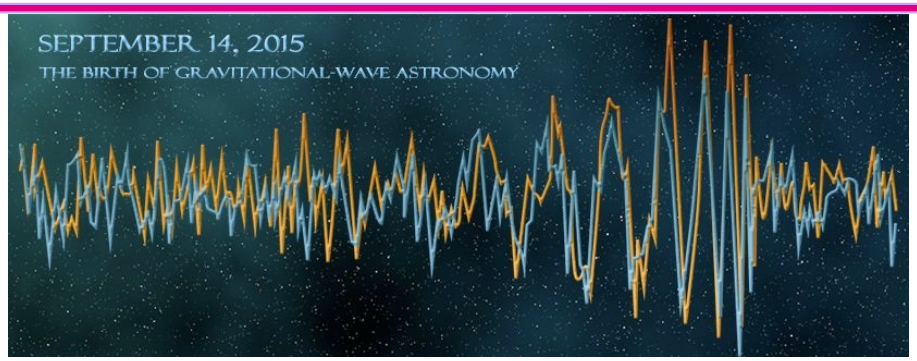
Gravitational Wave Astronomy



Gabriela González

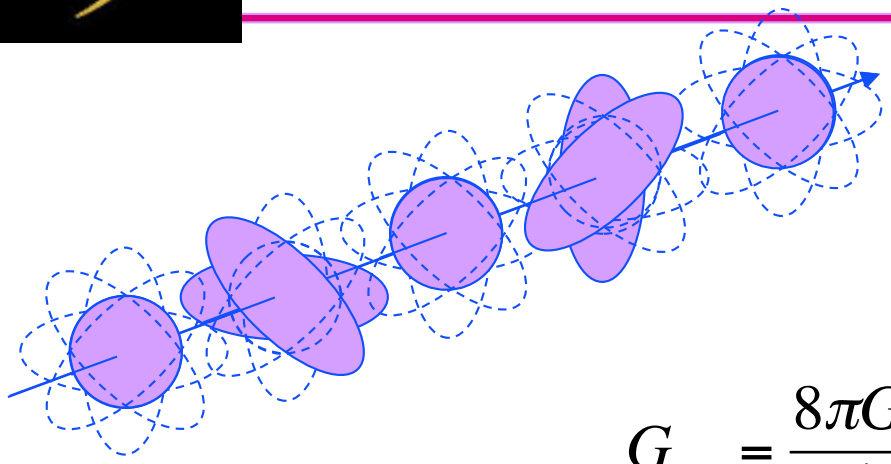
Louisiana State University

(Results presented on behalf of the LIGO Scientific Collaboration, the Virgo Collaboration and the KAGRA collaboration)

APS March Meeting

Kavli symposium, March 5, 2023

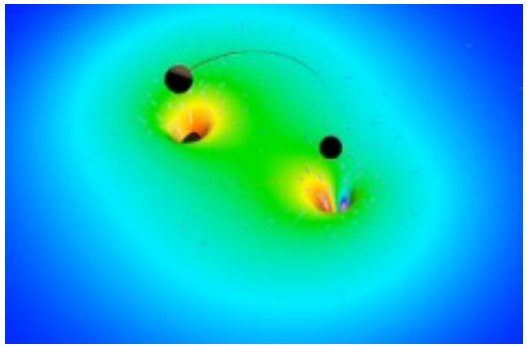
Gravitational waves: basic math



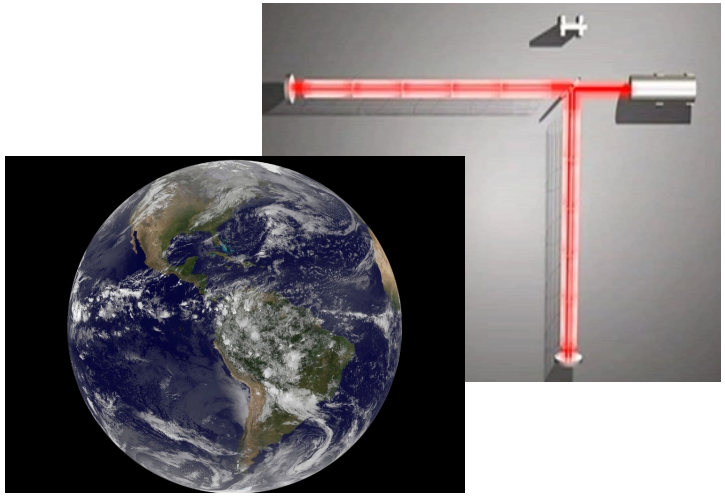
Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

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

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

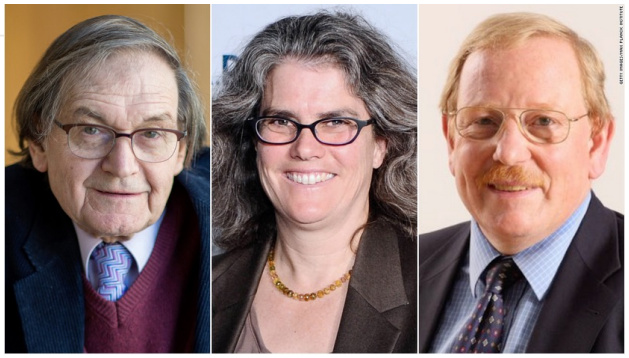


$$h_{\mu\nu} \sim \frac{2G}{c^4 r} \ddot{I}_{\mu\nu}$$



How to “see” black holes

Press release: The Nobel Prize in Physics 2020



English
English (pdf)
Swedish
Swedish (pdf)

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

6 October 2020

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2020

with one half to

Roger Penrose
University of Oxford, UK

“for the discovery that black hole formation is a robust prediction of the general theory of relativity”

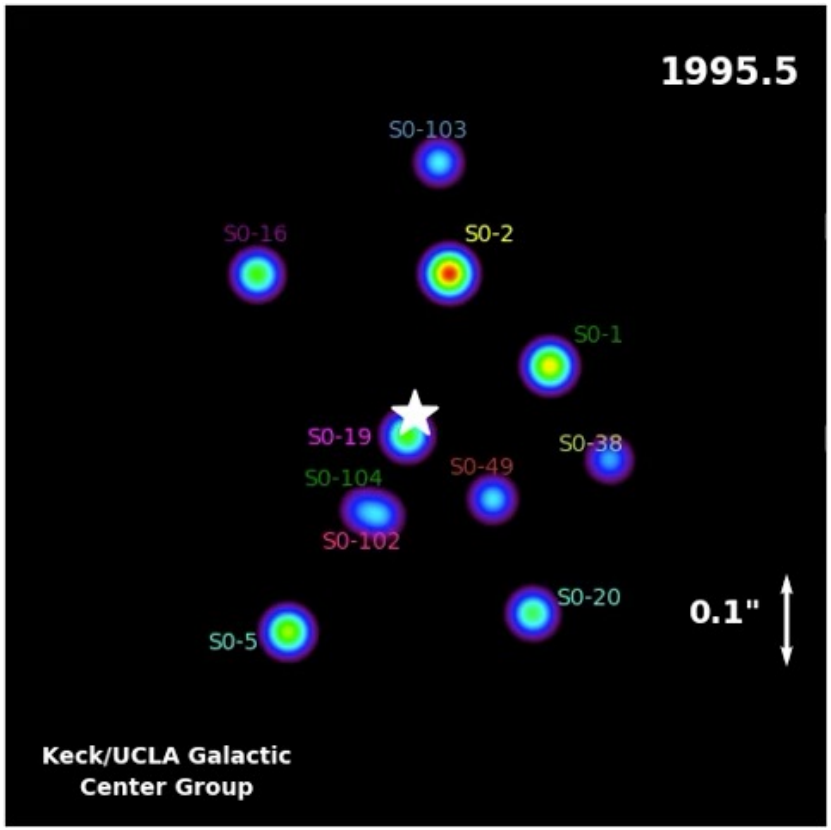
and the other half jointly to

Reinhard Genzel
Max Planck Institute for Extraterrestrial Physics, Garching, Germany and University of California, Berkeley, USA

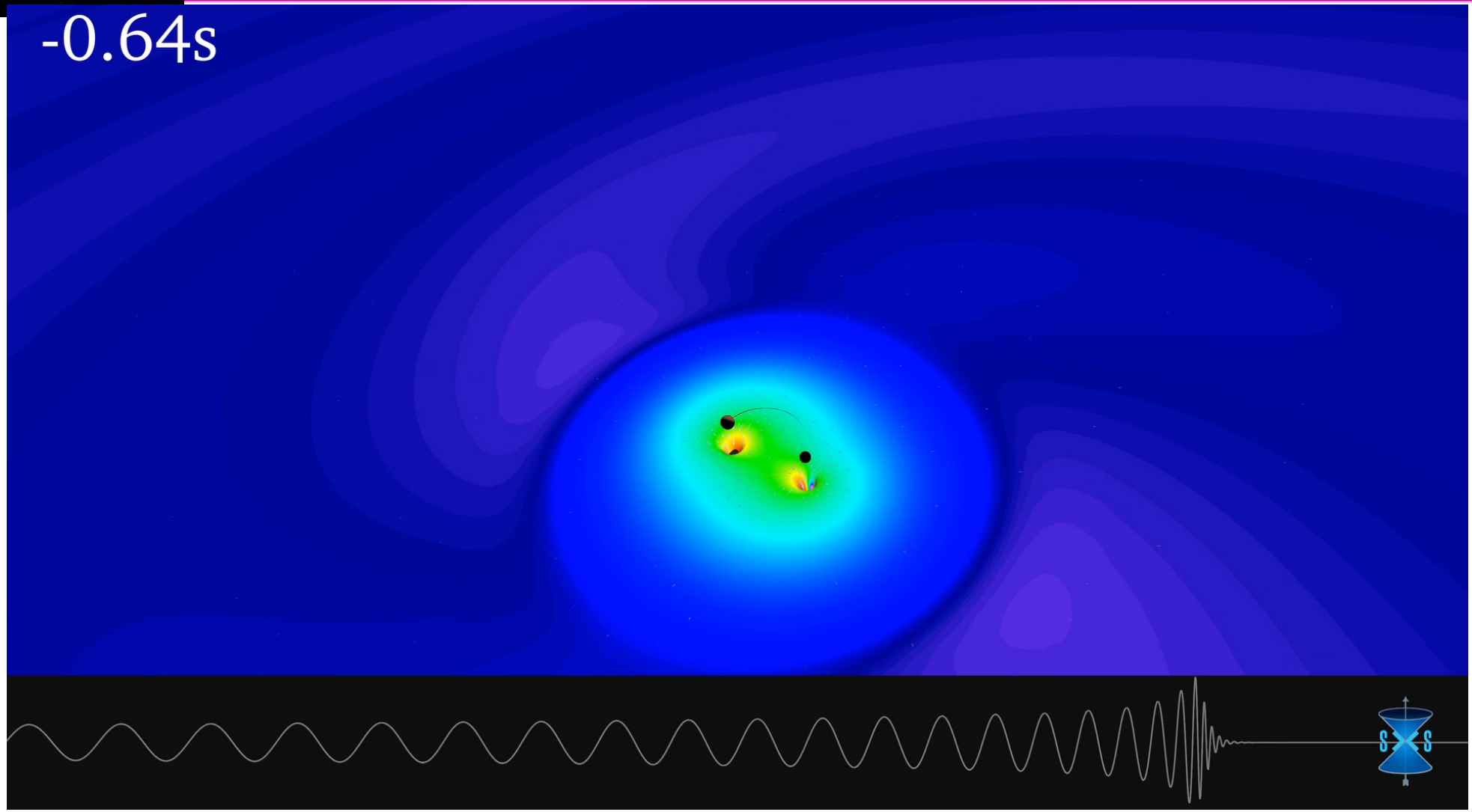
and

Andrea Ghez
University of California, Los Angeles, USA

“for the discovery of a supermassive compact object at the centre of our galaxy”

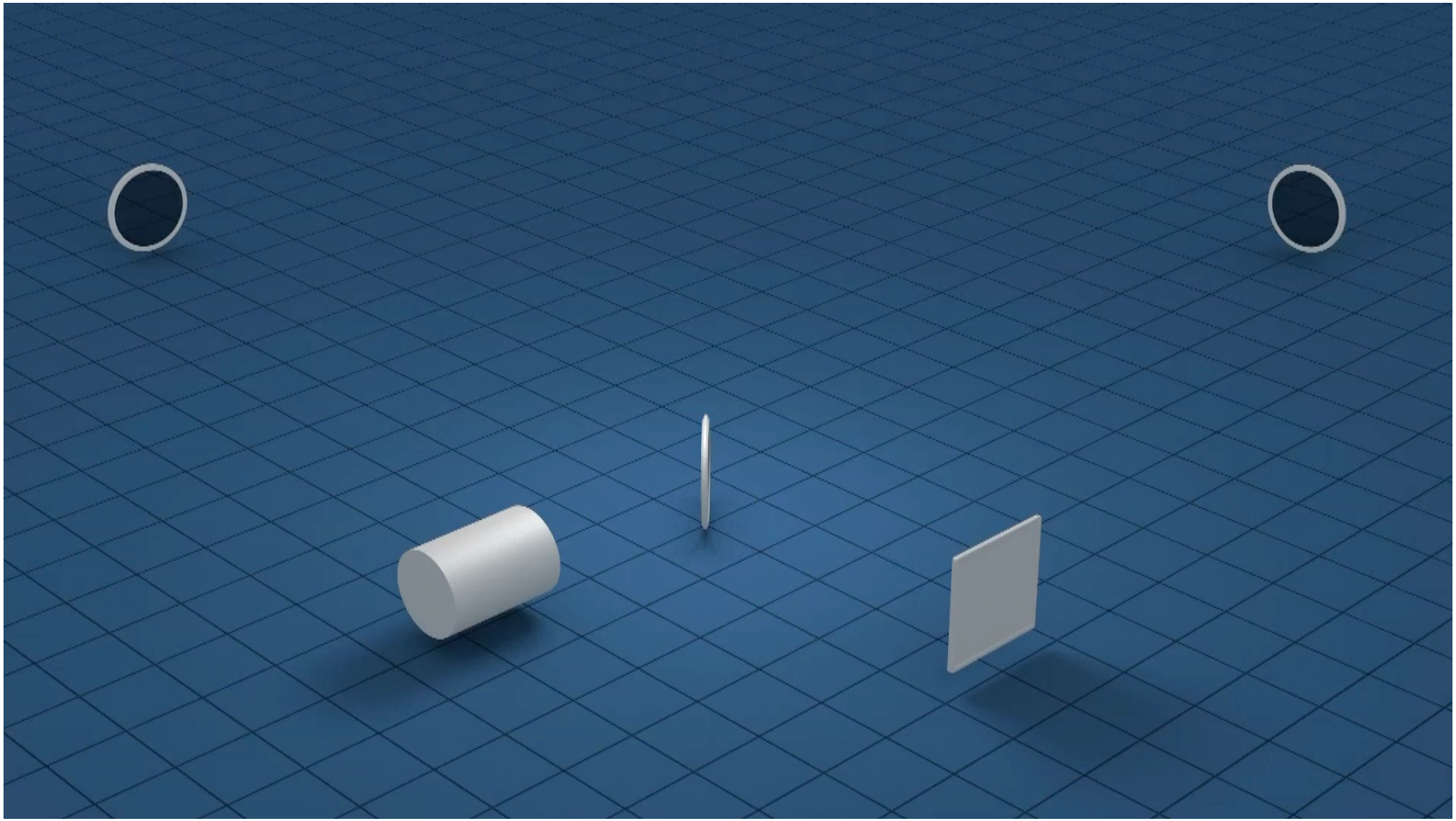


How to “hear” black holes – with gravitational waves



Credit: SXS

How to measure gravitational waves: interferometers



GW detectors network

LIGO Hanford

GEO600

LIGO Livingston

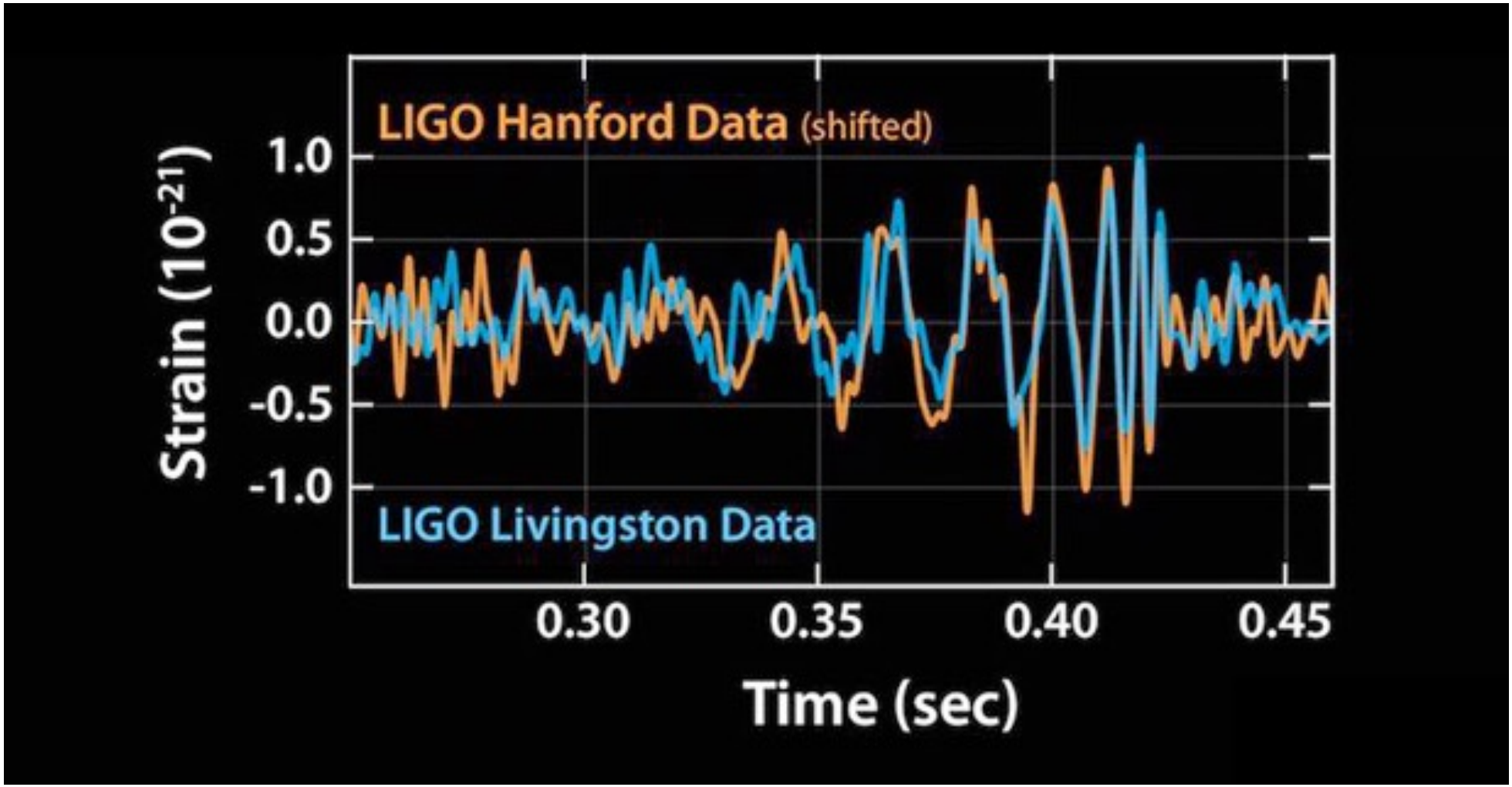
Virgo

KAGRA

LIGO India

Gravitational Wave Observatories

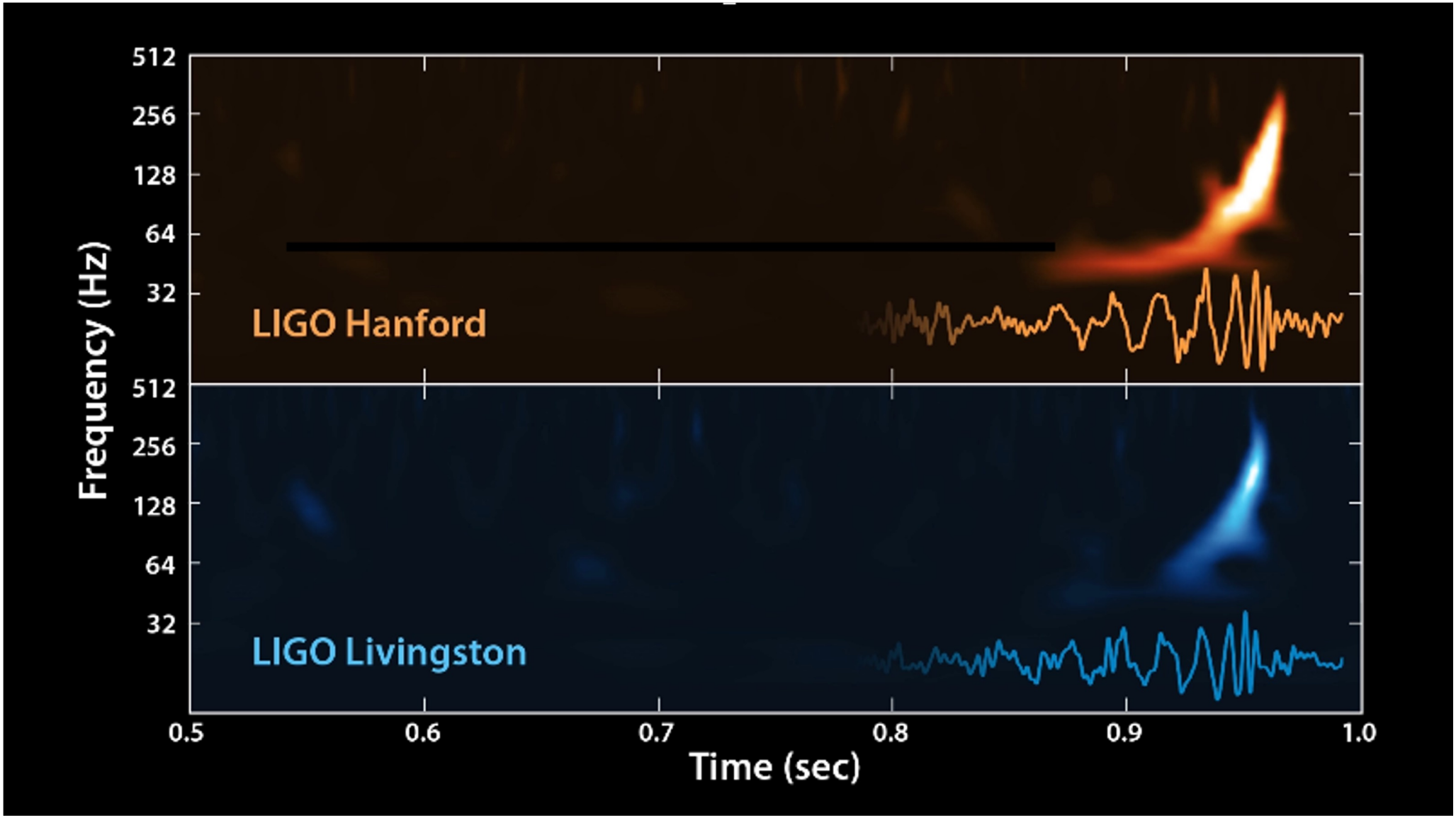
September 14 2015
A big surprise!



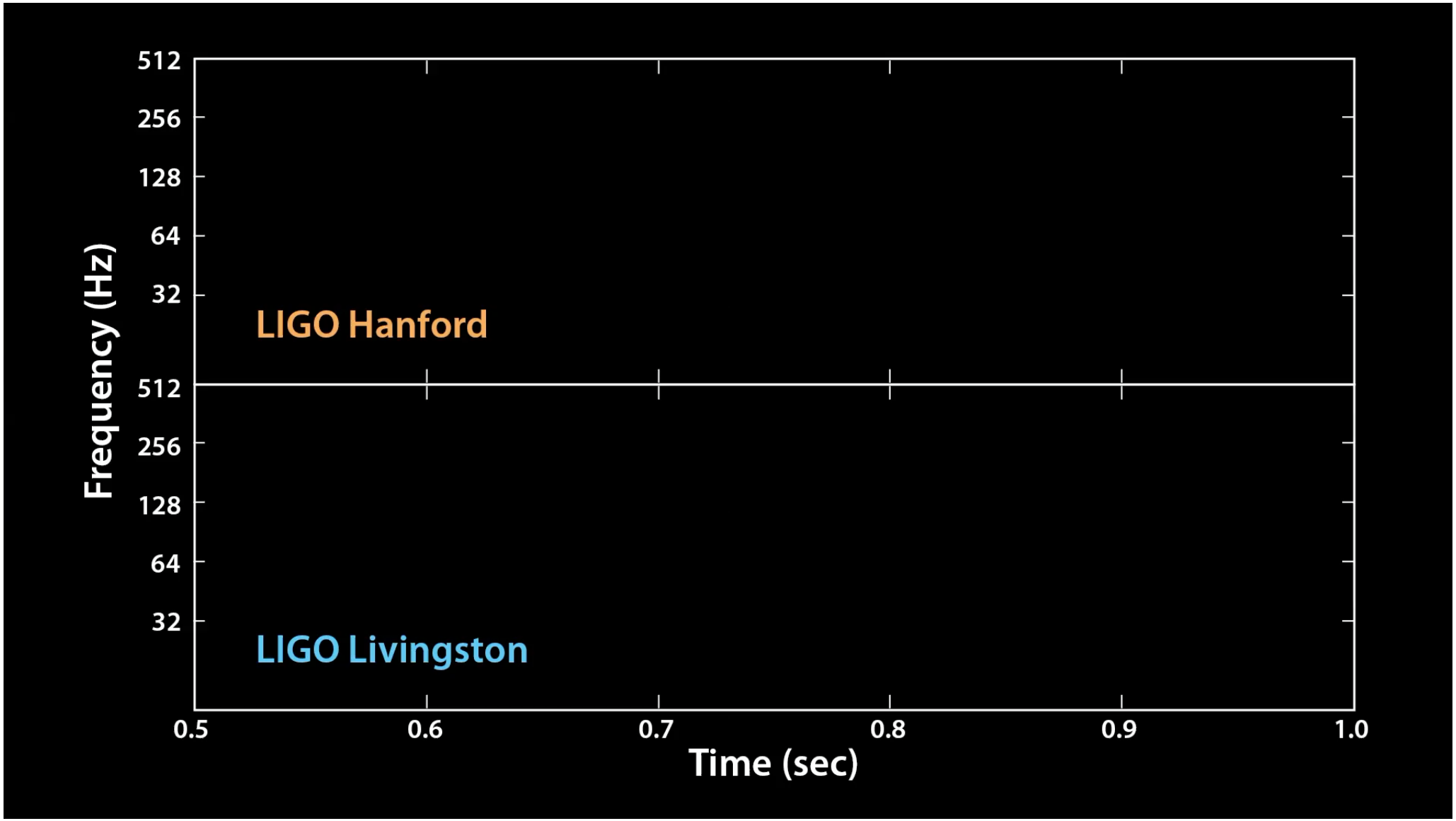
Credit: LIGO

February 11, 2016: We did it!

The music of the Universe



The music of the Universe



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THE ROYAL SWEDISH ACADEMY OF SCIENCES

English
English (pdf)

Swedish
Swedish (pdf)

LSU

Press Release: The Nobel Prize in Physics 2017

3 October 2017

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2017 with one half to

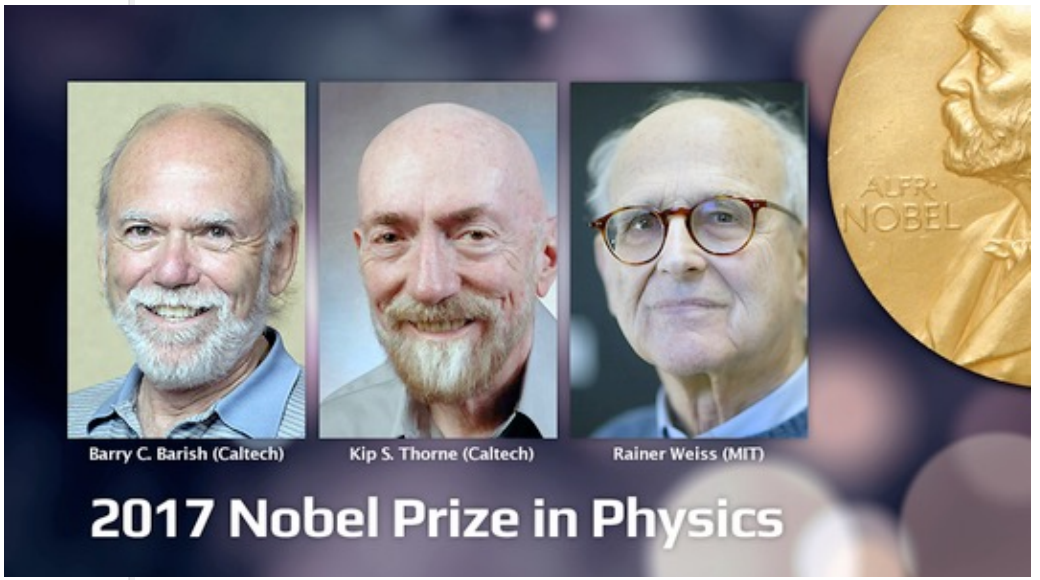
Rainer Weiss
LIGO/VIRGO Collaboration

and the other half jointly to

Barry C. Barish
LIGO/VIRGO Collaboration

and

Kip S. Thorne
LIGO/VIRGO Collaboration



"for decisive contributions to the LIGO detector and the observation of gravitational waves"

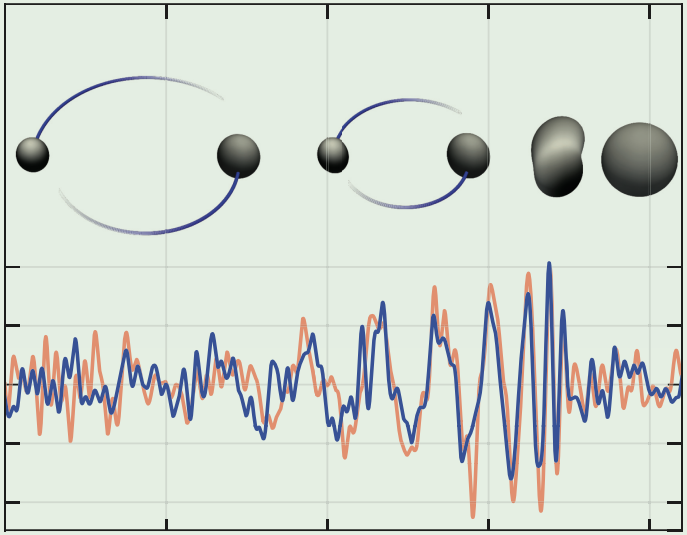
Gravitational waves finally captured

On 14 September 2015, the universe's gravitational waves were observed for the very first time. The waves, which were predicted by Albert Einstein a hundred years ago, came from a collision between two black holes. It took 1.3 billion years for the waves to arrive at the LIGO detector in the USA.

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

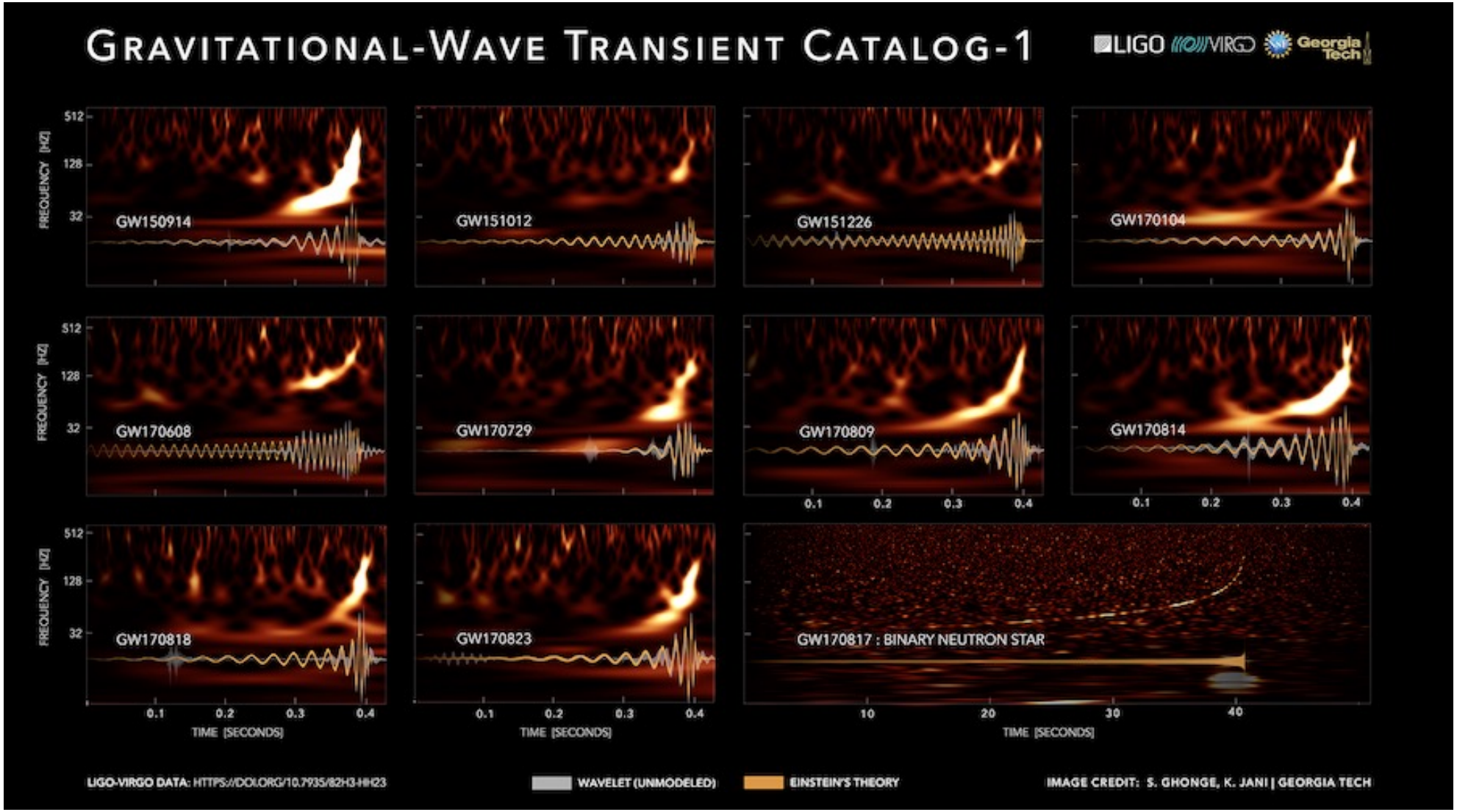
Observation of Gravitational Waves from a Binary Black Hole Merger

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

2015-2017: 11 detections

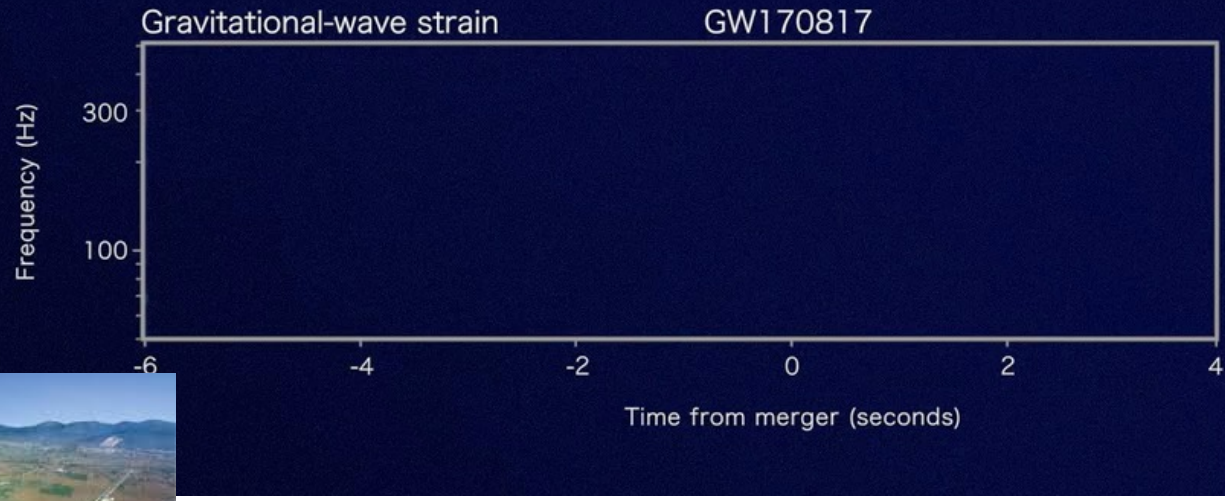


Phys. Rev. X **9**, 031040 (2019)

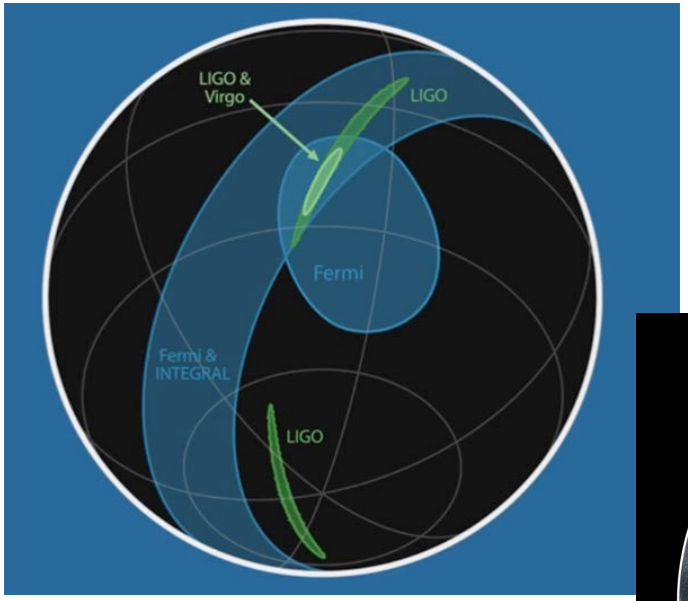
GW170817: fireworks too!

Fermi

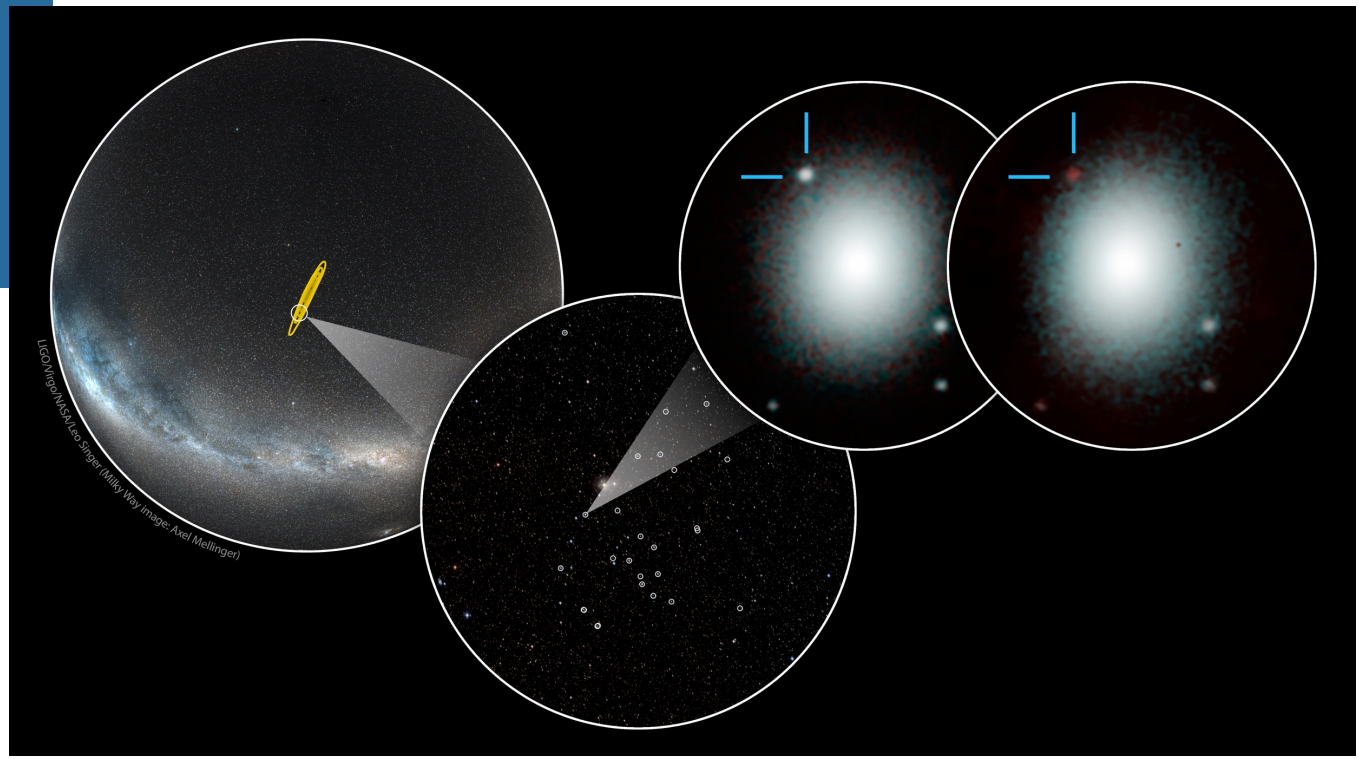
LIGO



And a galaxy had a new bright spot

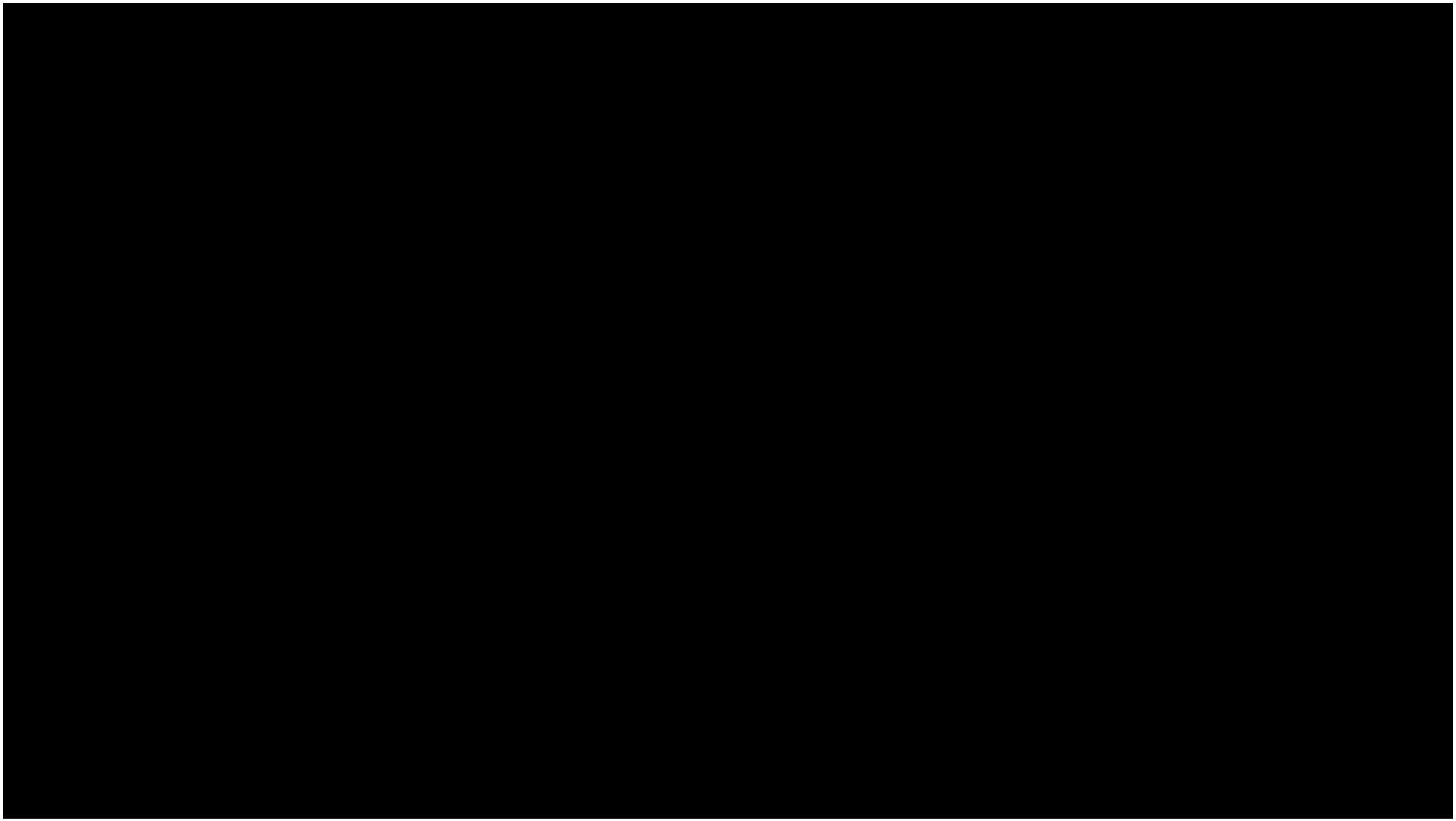


Credit: LIGO/Virgo



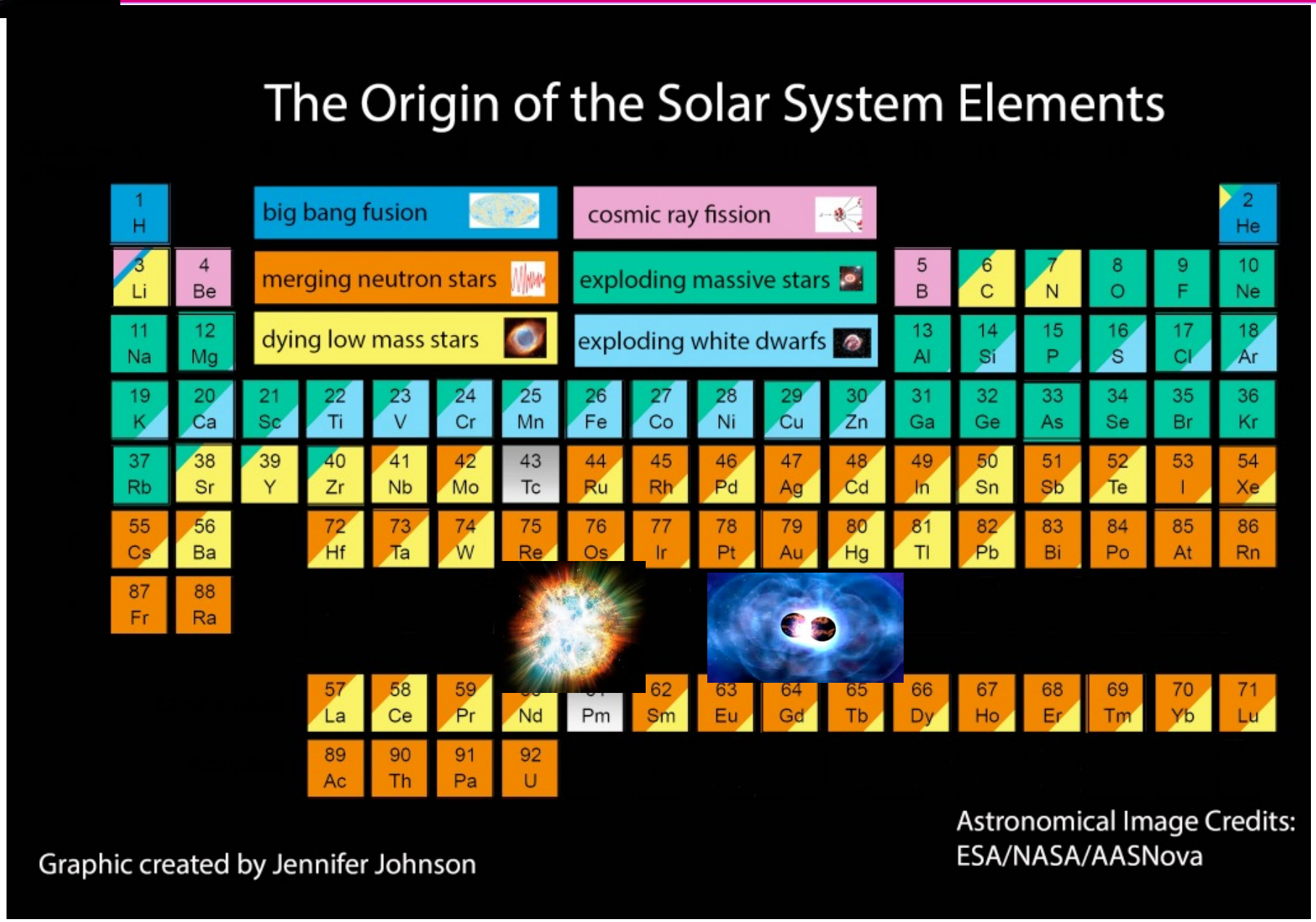
Credit: GROWTH collaboration

Binary Neutron Star merger: the movie



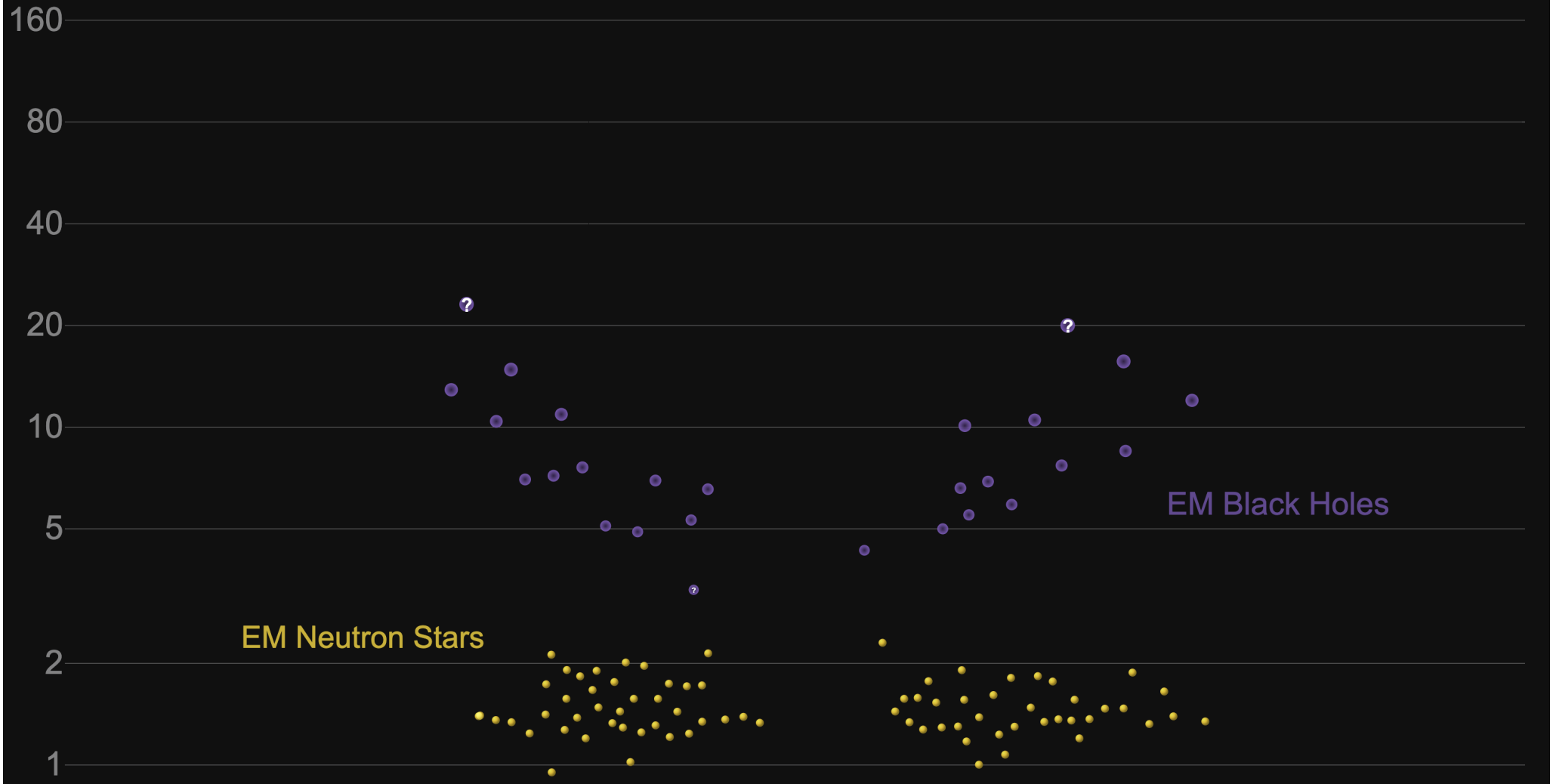
Credit: NASA/Goddard Space Flight Center

We are made of star stuff

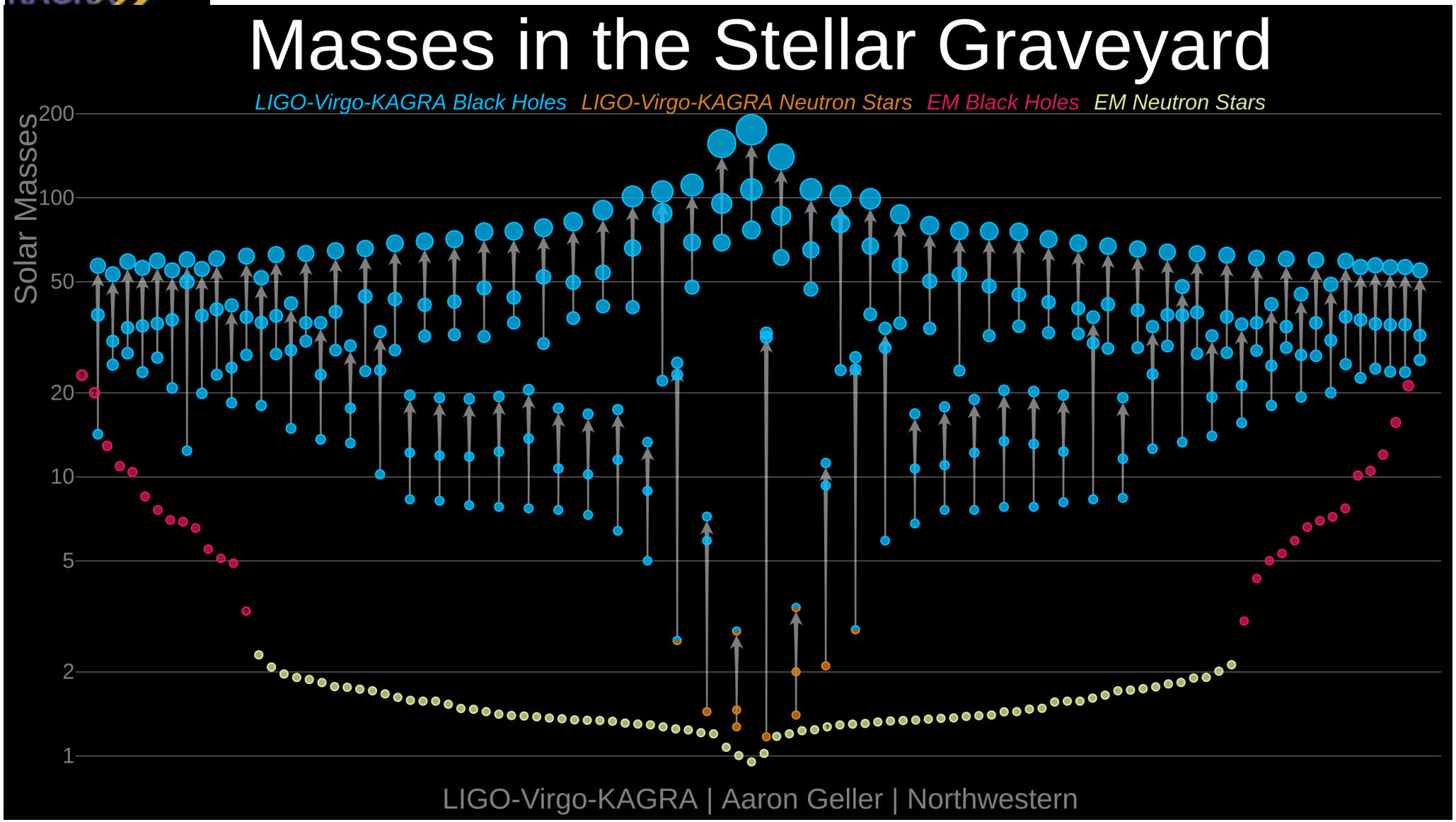


Masses in the Stellar Graveyard

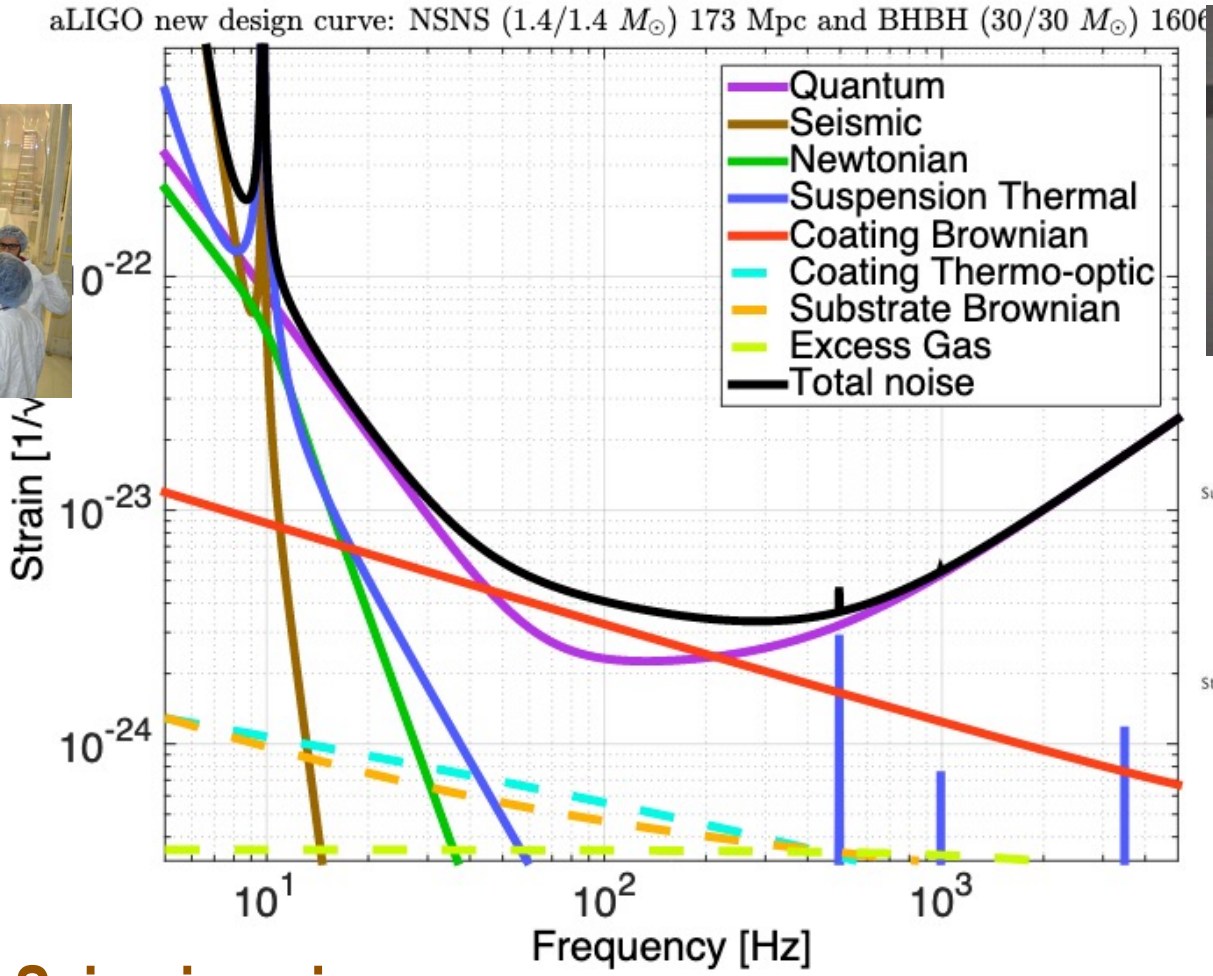
in Solar Masses

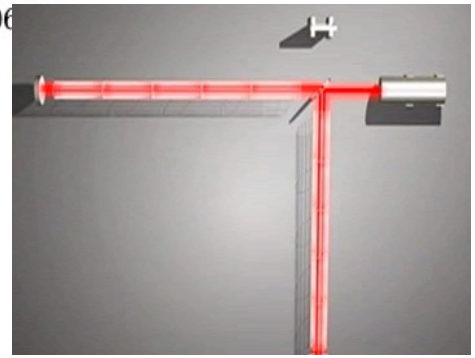


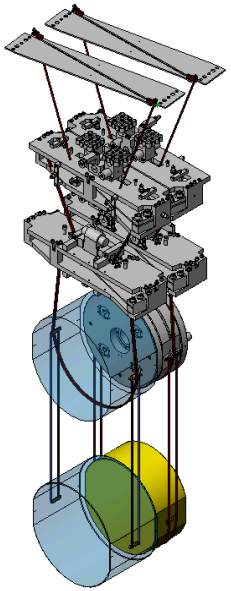
Masses in the Stellar Graveyard

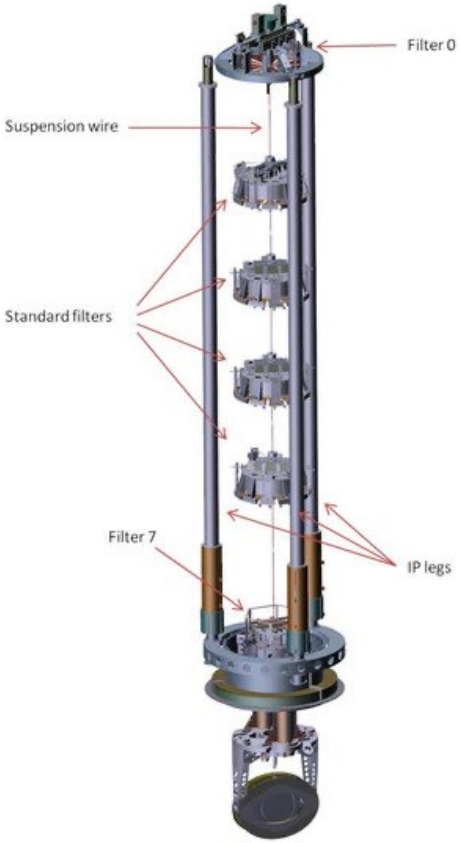


Projected noise in Advanced LIGO



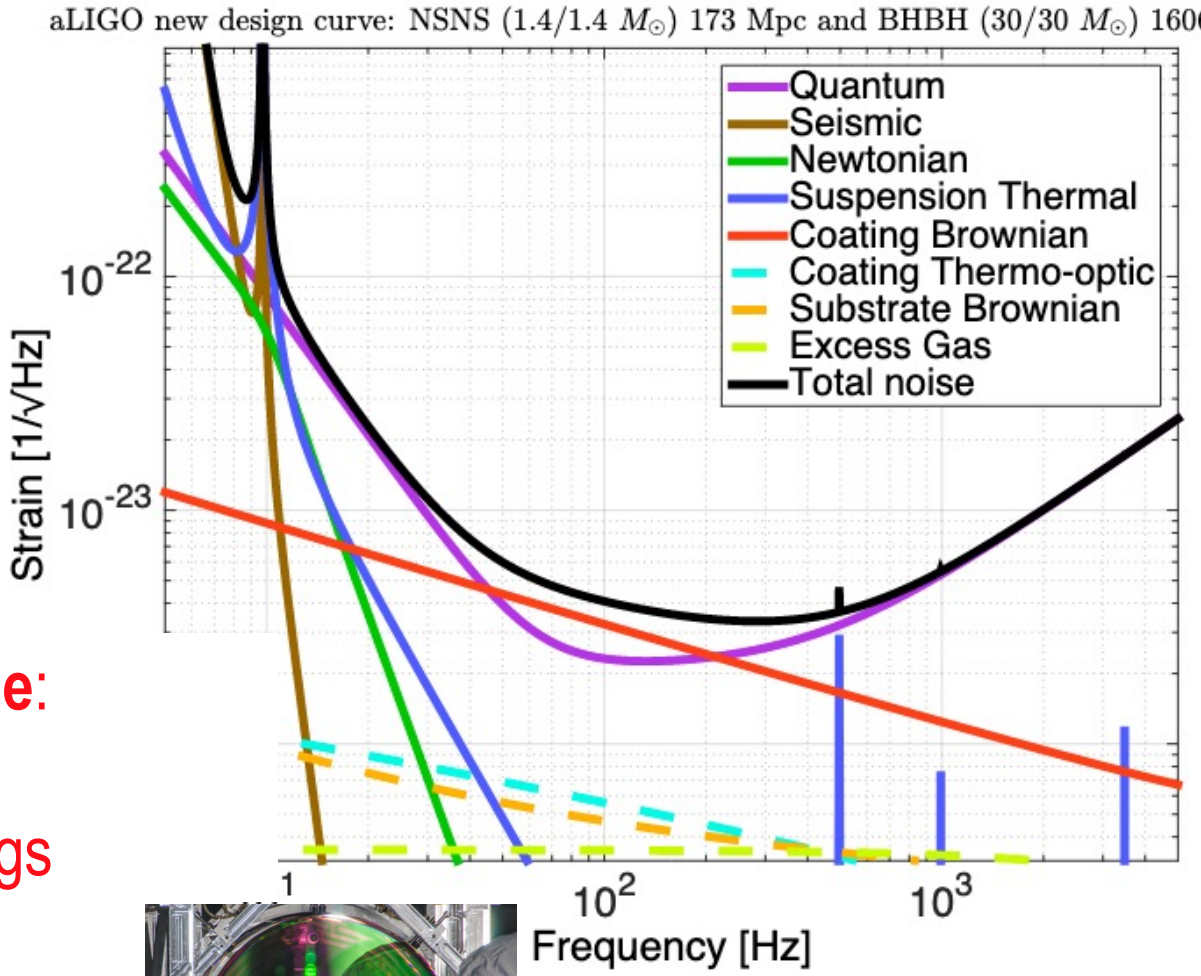


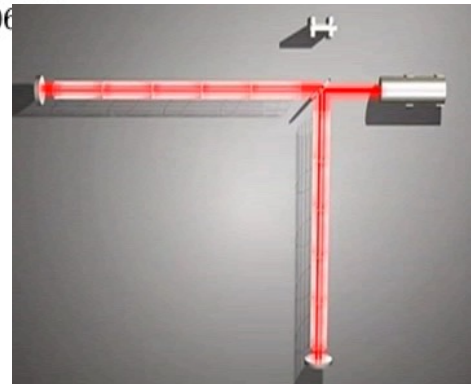




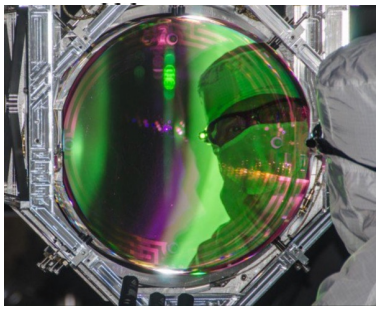
Seismic noise:
multiple pendulums,
active seismic isolation

Projected noise in Advanced LIGO

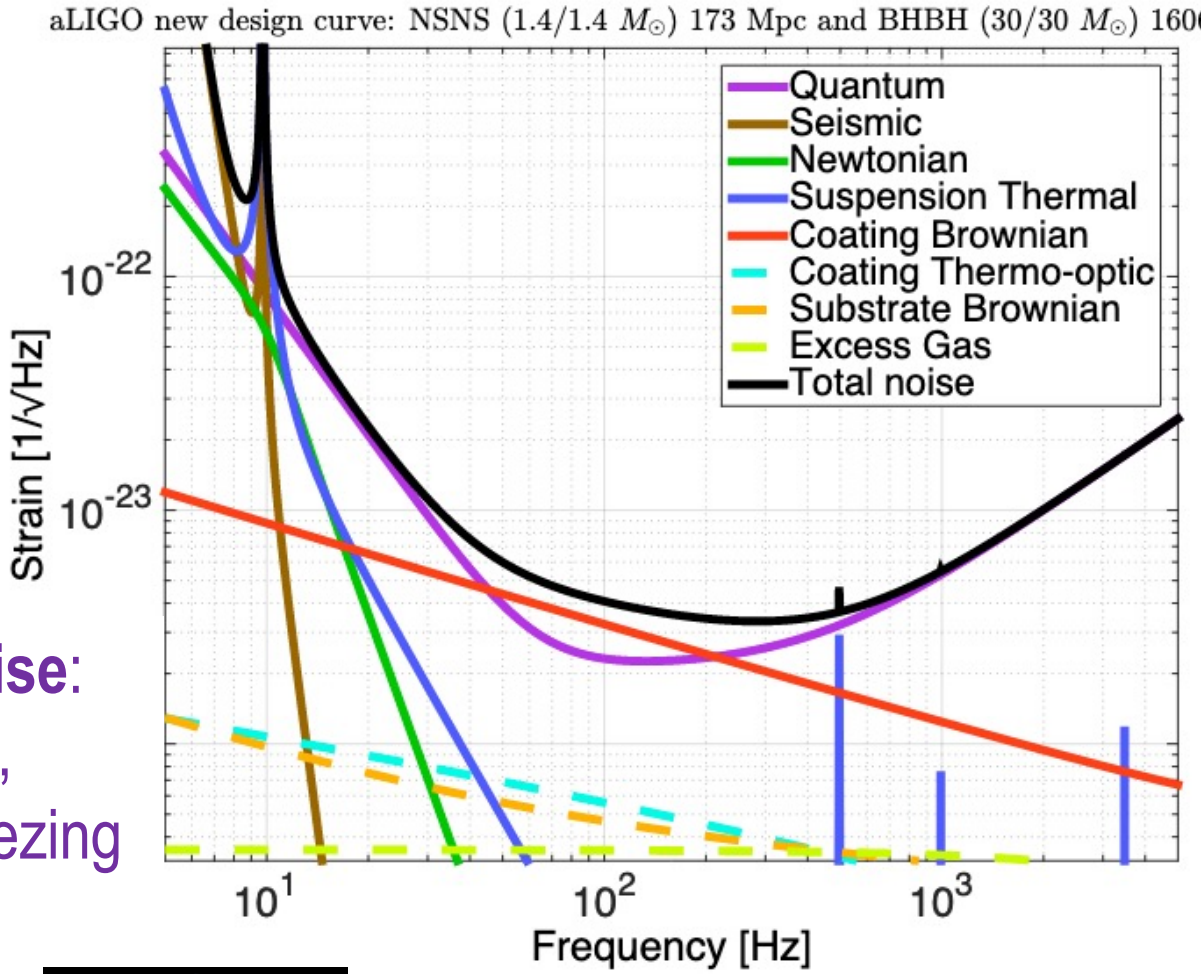


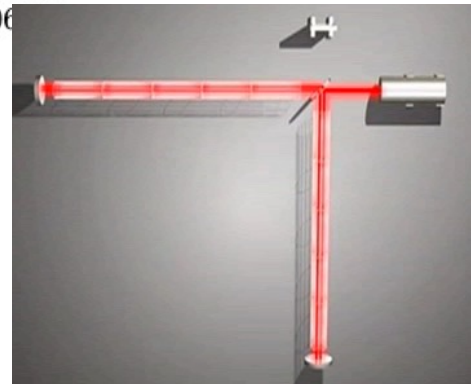


Thermal noise:
less lossy
mirrors/coatings

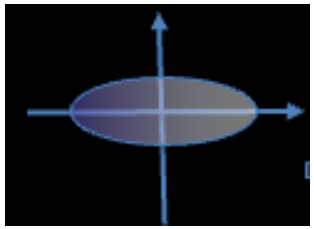


Projected noise in Advanced LIGO

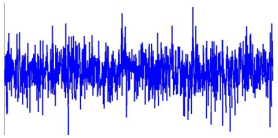


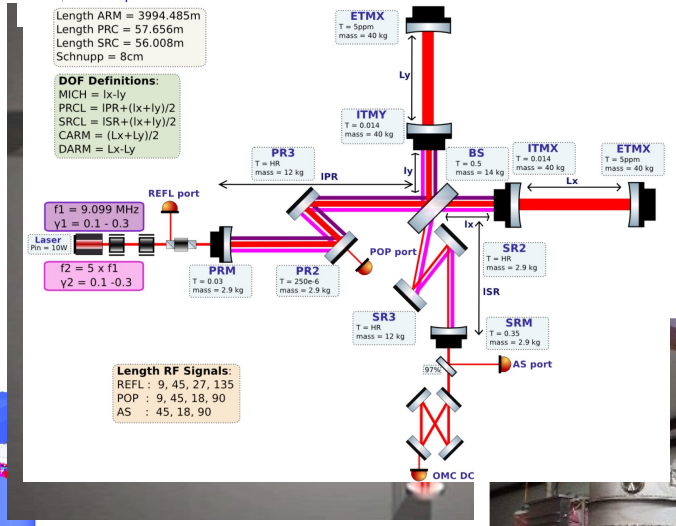


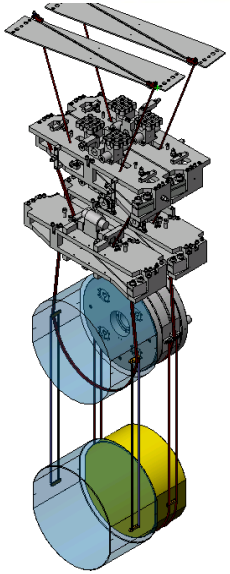
Quantum Noise:
more photons,
vacuum squeezing

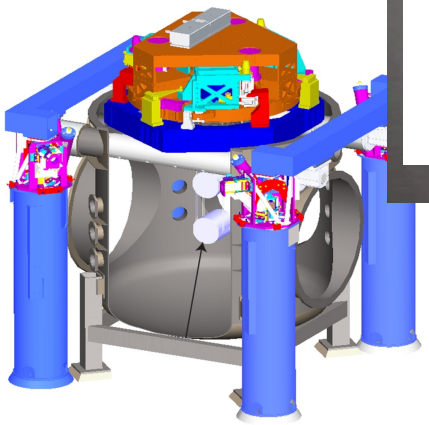


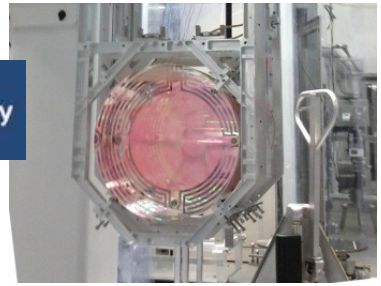
Advanced LIGO detectors







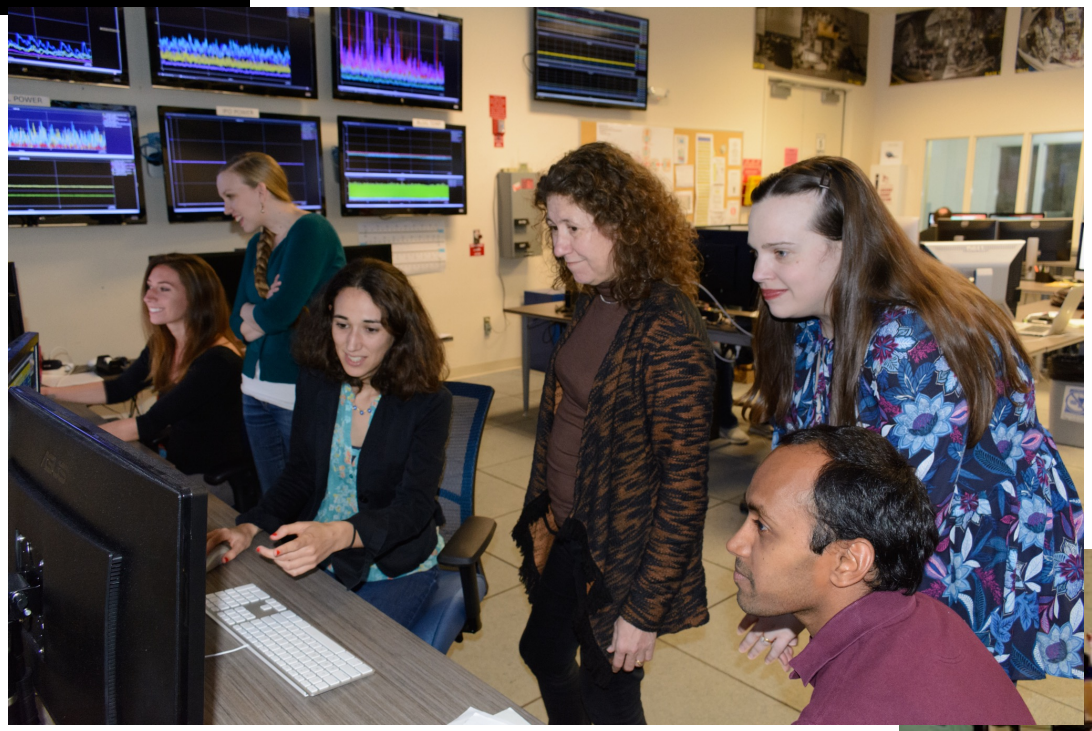




Science & Technology Facilities Council

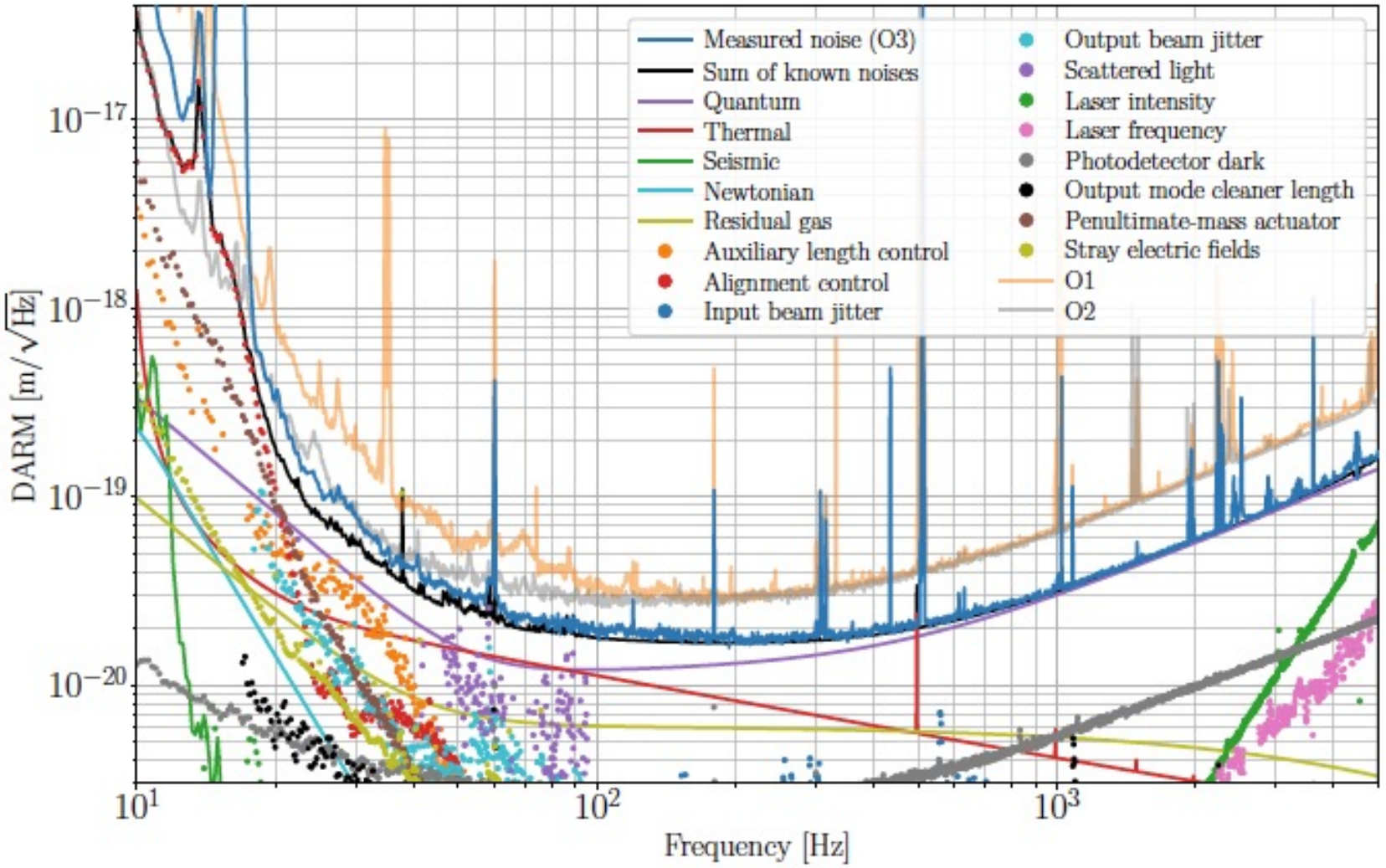
NSF

LIGO detectors: very complex instruments



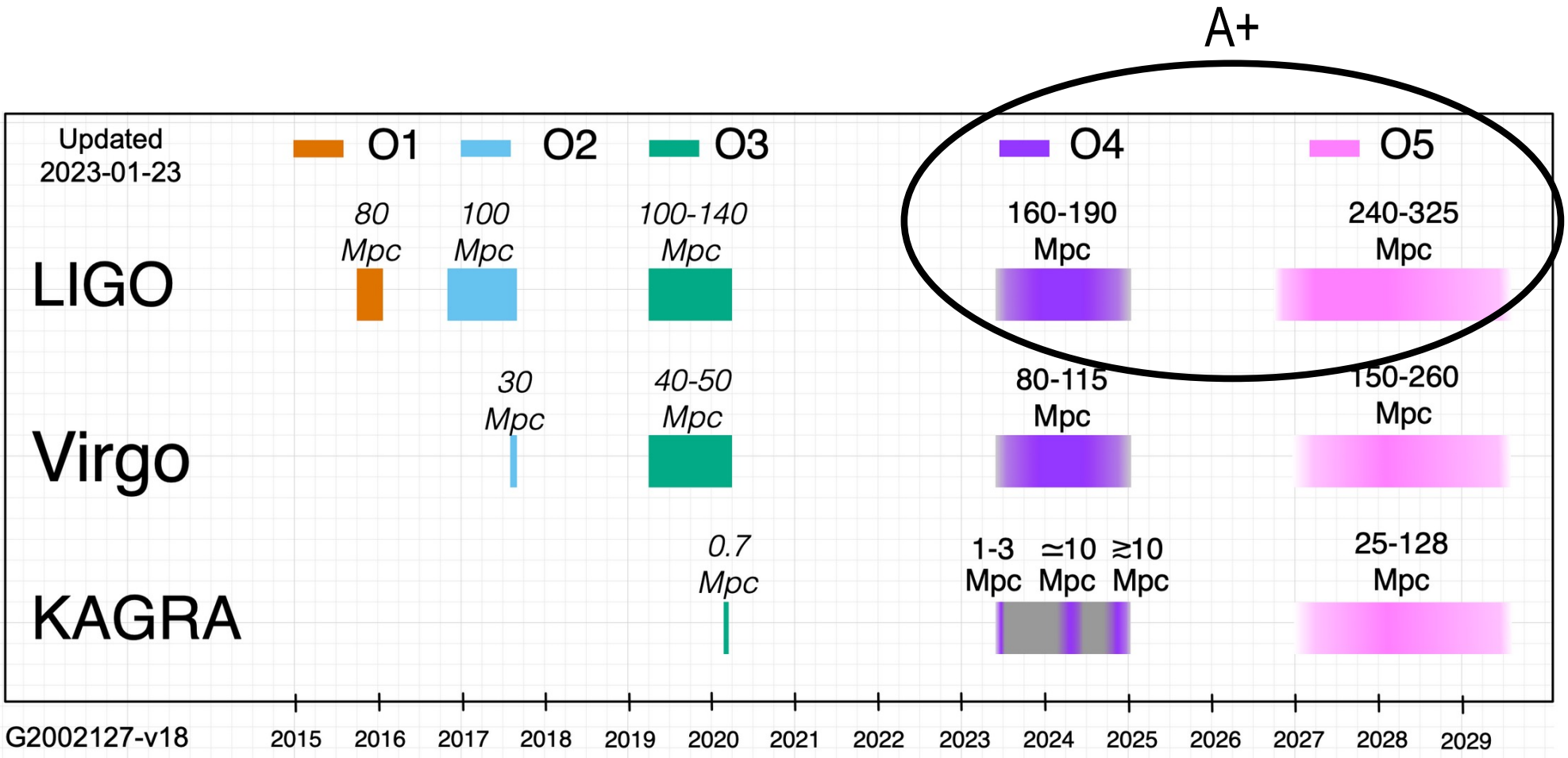
Reducing the noise, increasing the rate of detections

LIGO Livingston Detector



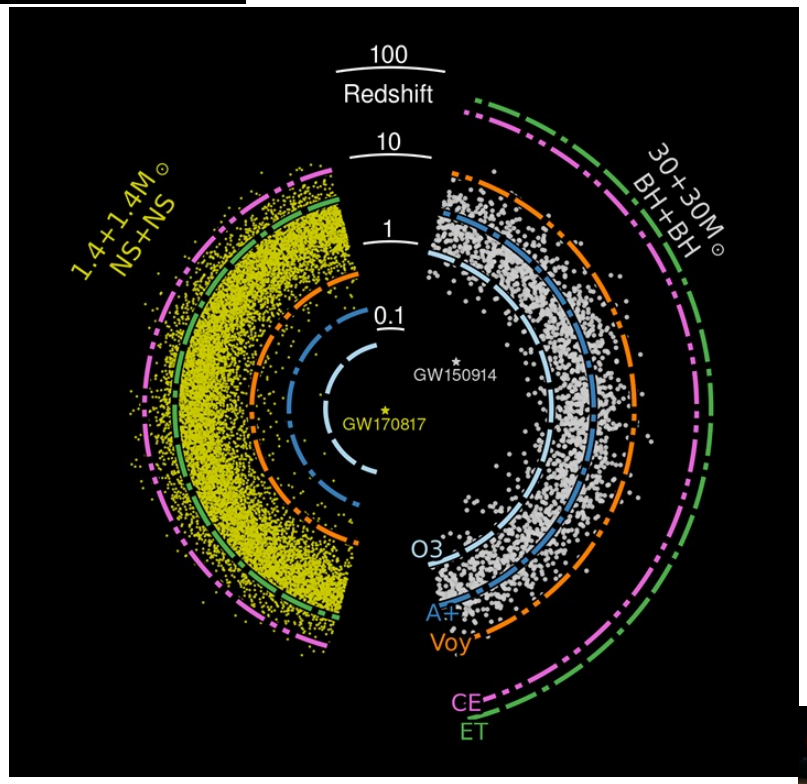
Phys. Rev. D 102, 062003 (2020)

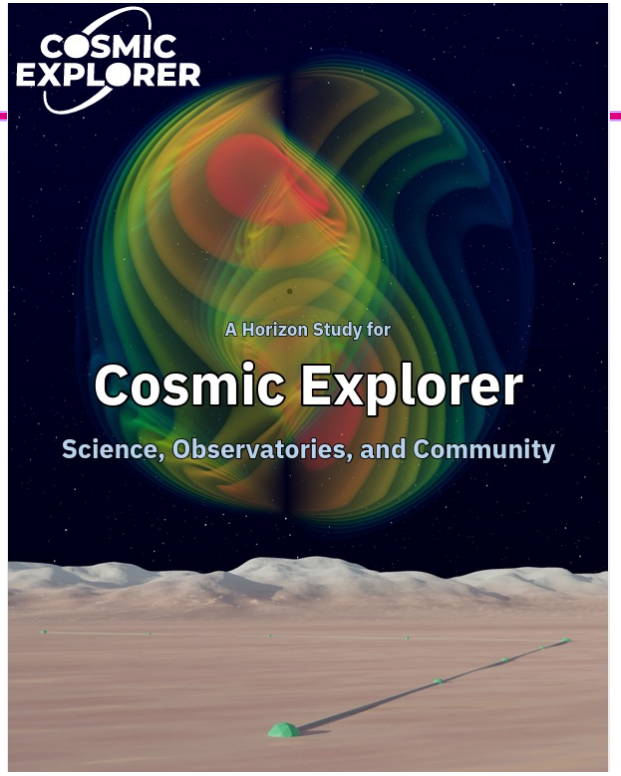
Past and future LVK Observing Runs



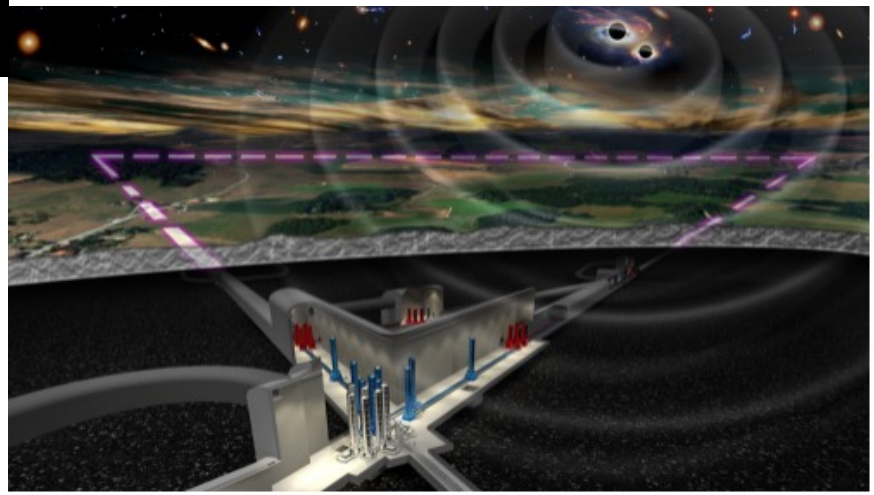
https://observing.docs.ligo.org/plan/

Third Generation Detectors (Ground based)



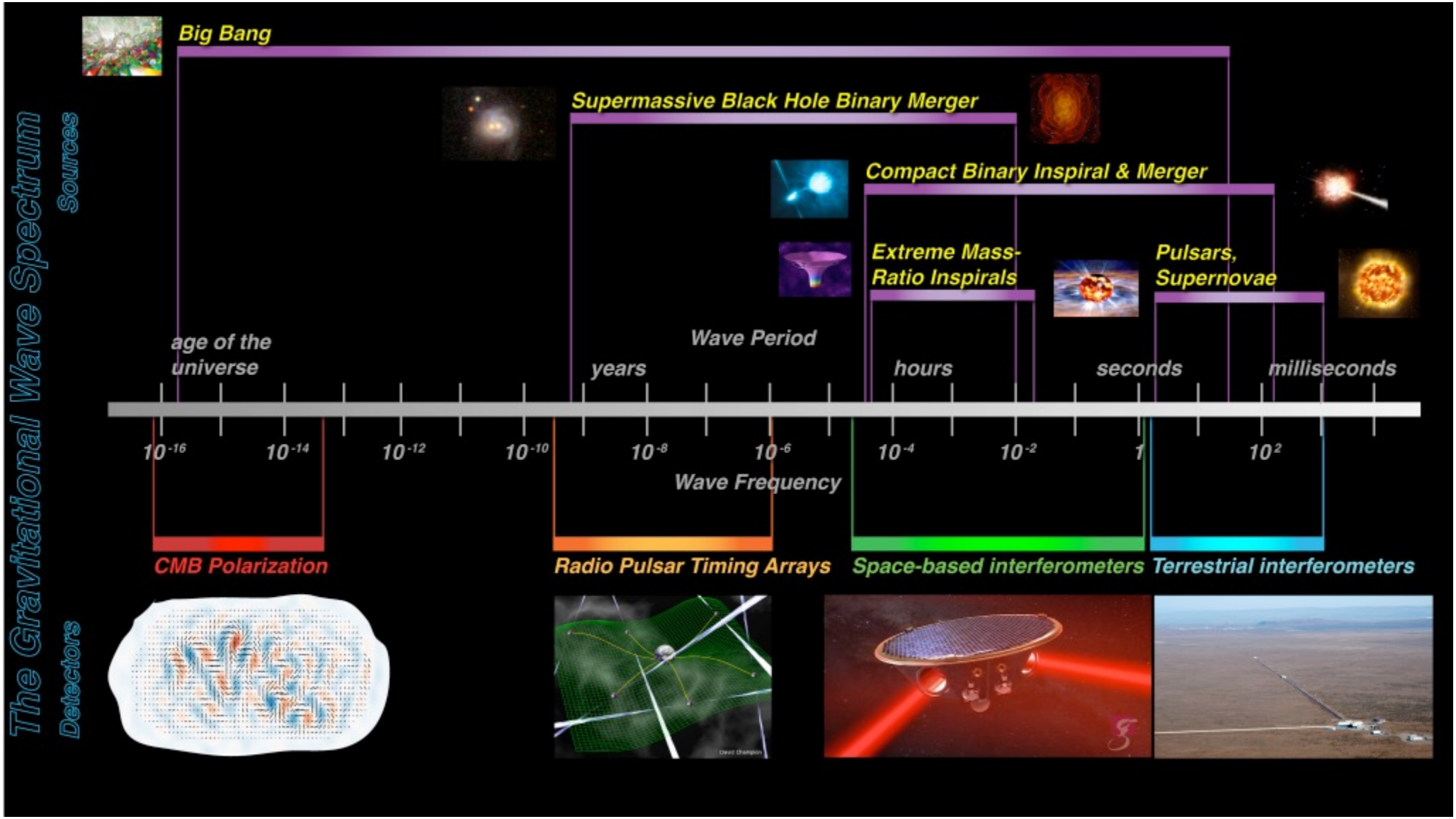


https://cosmicexplorer.org/

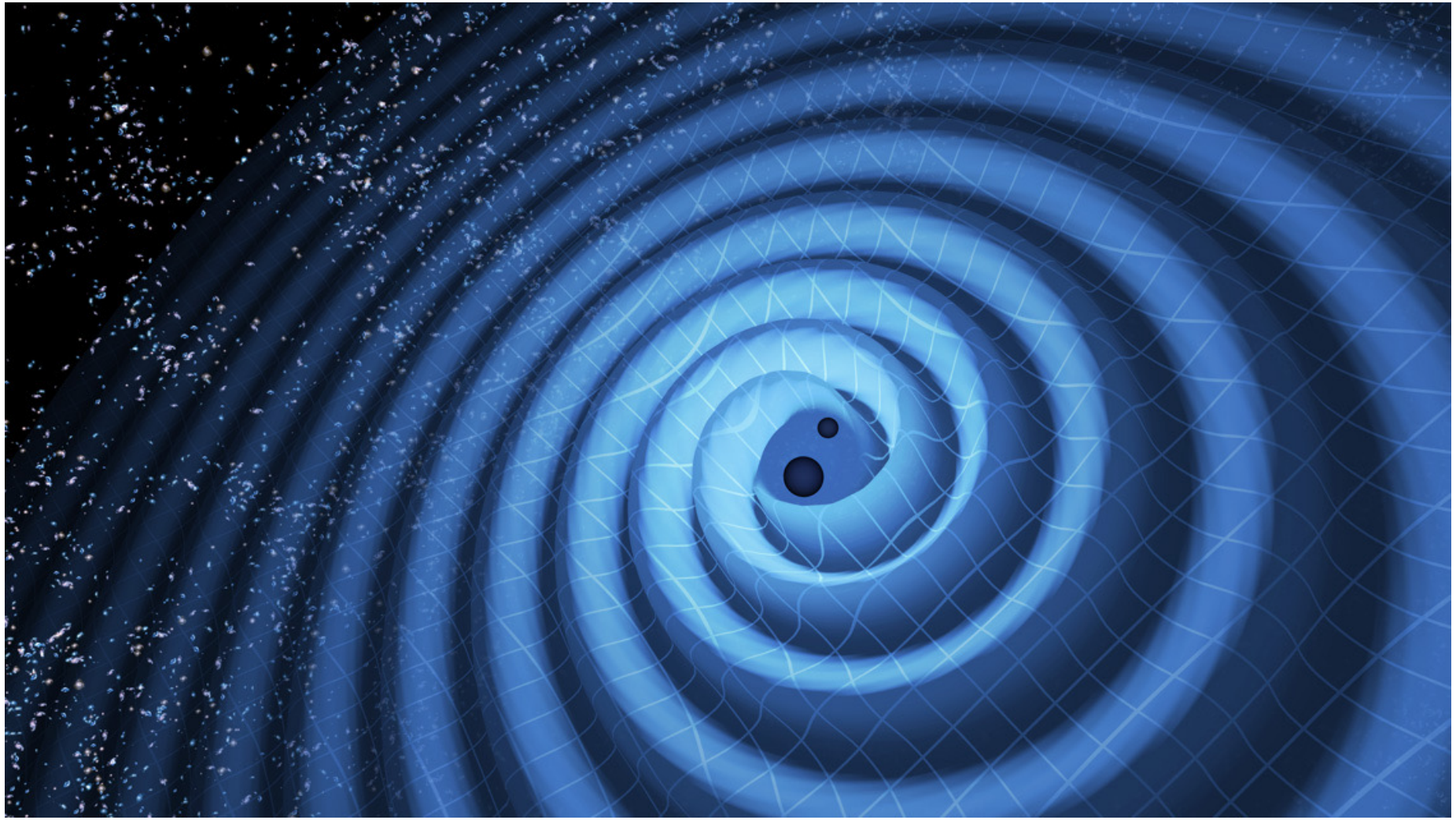


http://www.et-gw.eu/

Different wavelengths need different instruments



Gravitational waves astronomy: this is just the beginning!



www.ligo.org

gonzalez@lsu.edu