LIGO and discovery of the gravitational waves

and

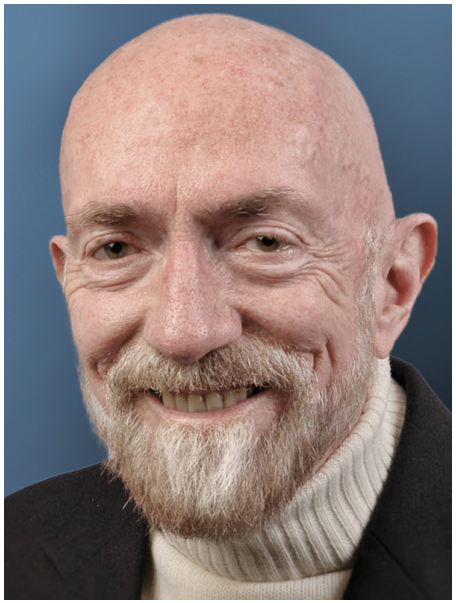
Eugeniy E. Mikhailov

April 13, 2018

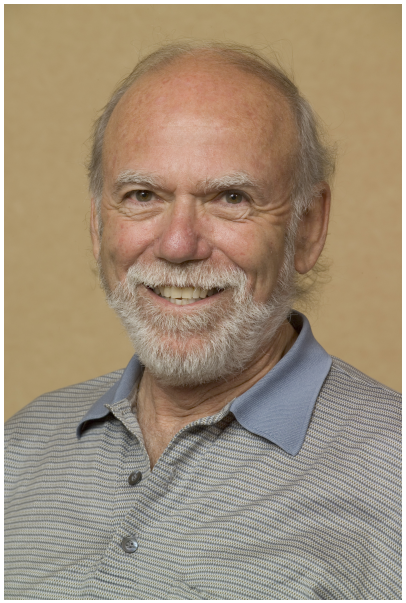
2017/10/03 Nobel prize in Physics

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

Rainer Weiss



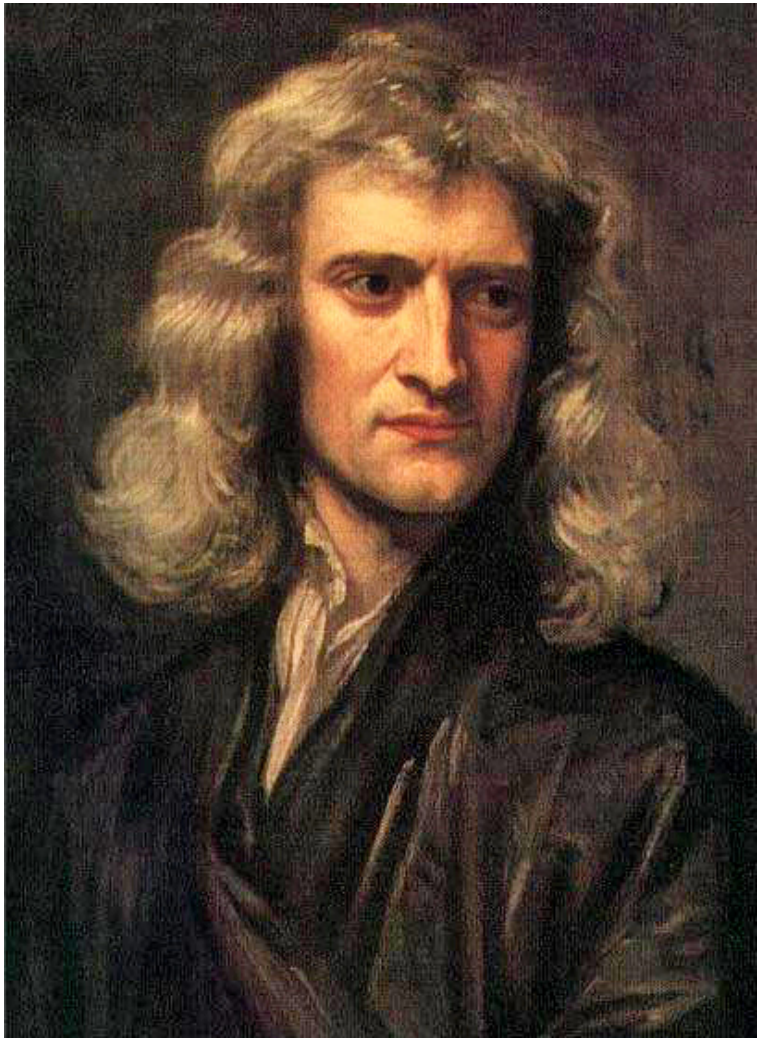
Kip S. Thorne



Barry C. Barish

LIGO Scientific Collaboration

Newton's laws 1686



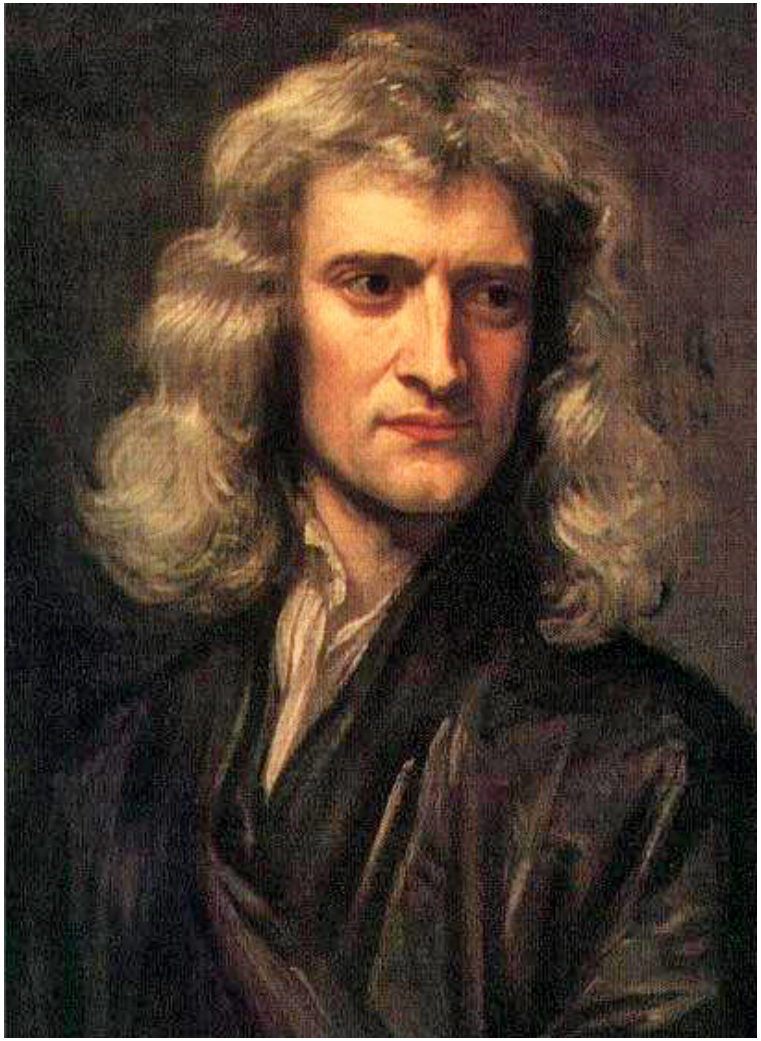
$$F_g = G\frac{m_1 m_2}{r^2}$$

Laws of motion and law of gravitation solved problems of astronomy and terrestrial physics.

- eccentric orbits
- tides
- perturbation of moon orbit due to sun

Unified the work of Galileo, Copernicus and Kepler.

Newton's laws 1686



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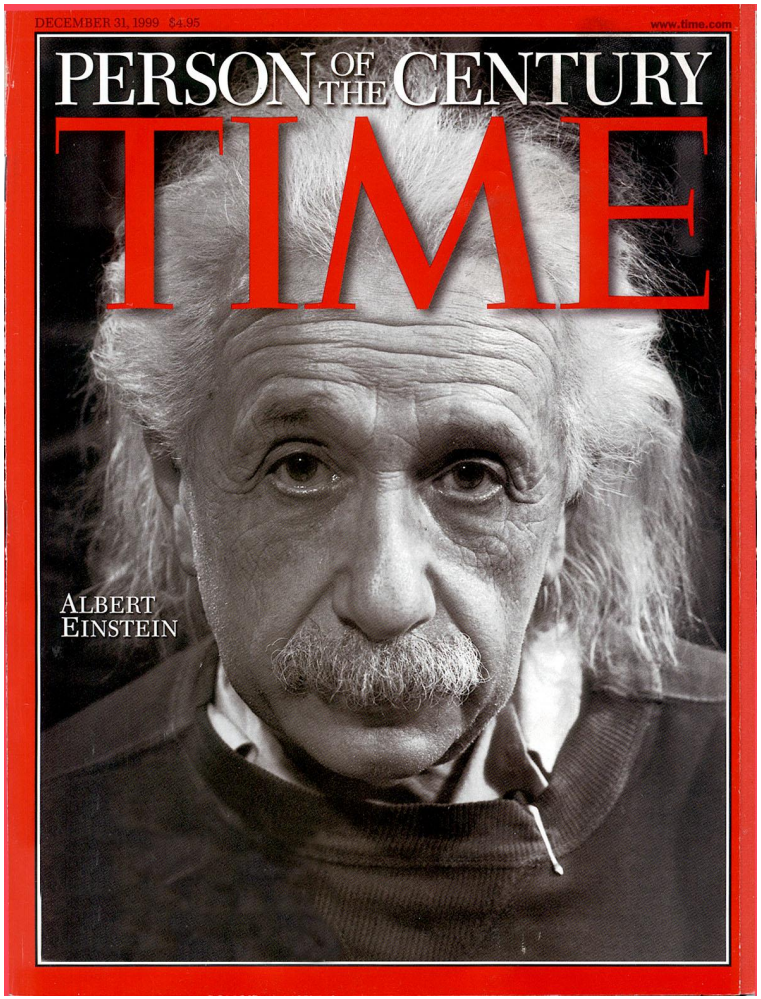
Time is not in the formula

Einstein's laws 1915

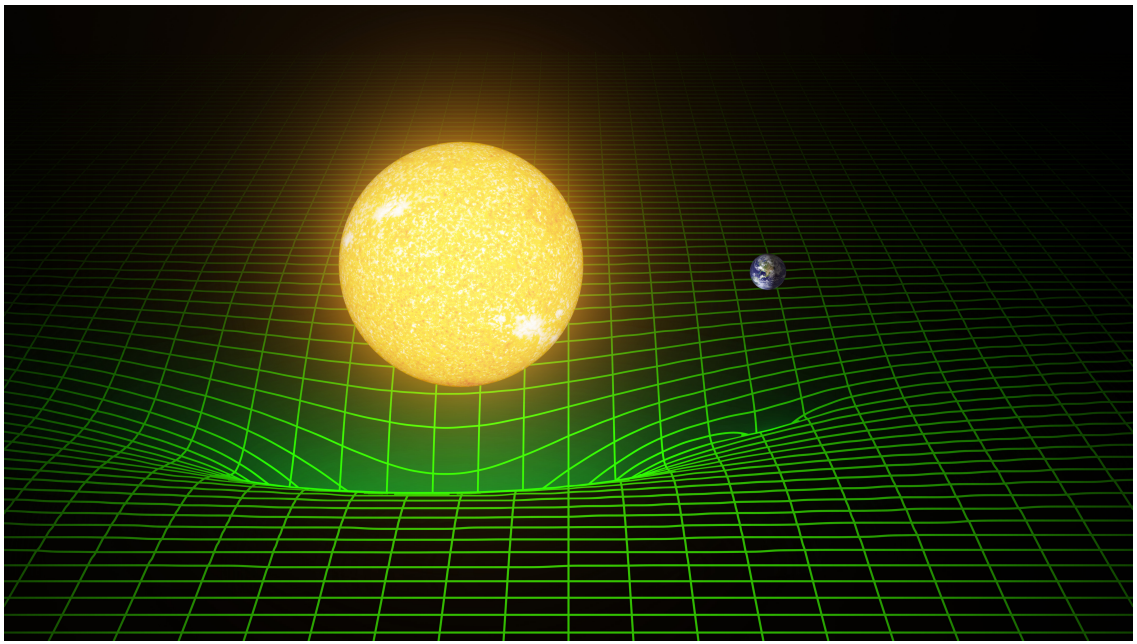


The General Theory of Relativity and theory of Gravity (1915)

- No absolute motion
  thus only relative motion
- Space and time are not separate
  thus four dimensional space-time
- Gravity is not a force acting at a distance
  thus warpage of space-time

General relativity

- A geometric theory connecting matter to spacetime
- Matter tells spacetime how to curve
- Spacetime tells matter how to move

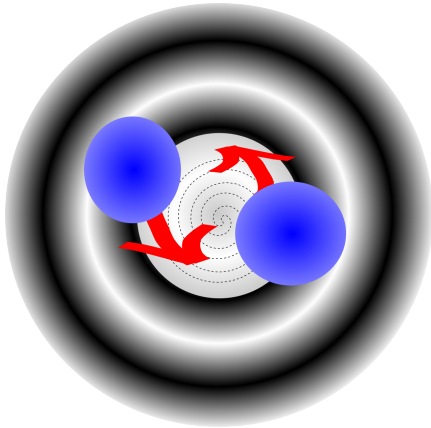


important predictions

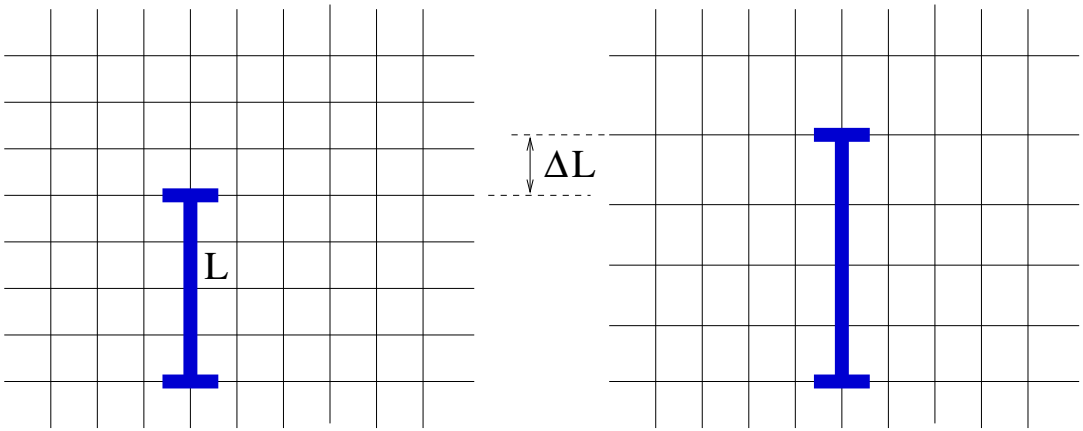
- Light path bends in vicinity of massive object $\rightarrow$ confirmed in 1919
- Gravitational radiation (waves) $\rightarrow$ confirmed indirectly in 1974

Gravitational waves (GW)

- Predicted by the General Theory of Relativity
- Generated by aspherical mass distribution
- Induce space-time ripples which propagate with speed of light



GW stretch and squeeze space-time thus move freely floating objects



Strain - strength of GW

$$h = \frac{\Delta L}{L} \qquad (1)$$

expected strain

$$h \sim 10^{-21} \qquad (2)$$

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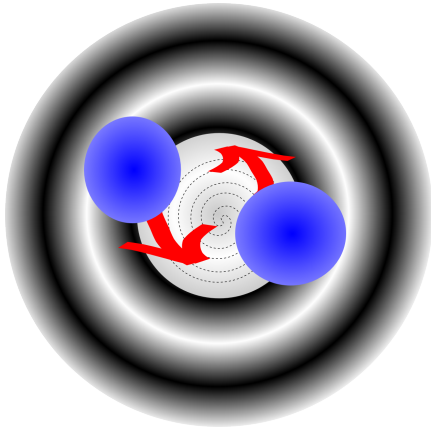

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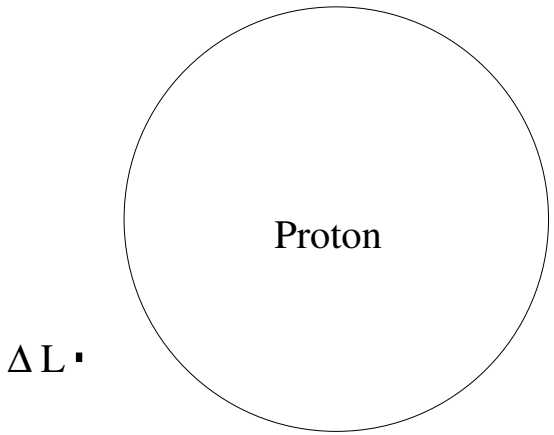

Strain - strength of GW

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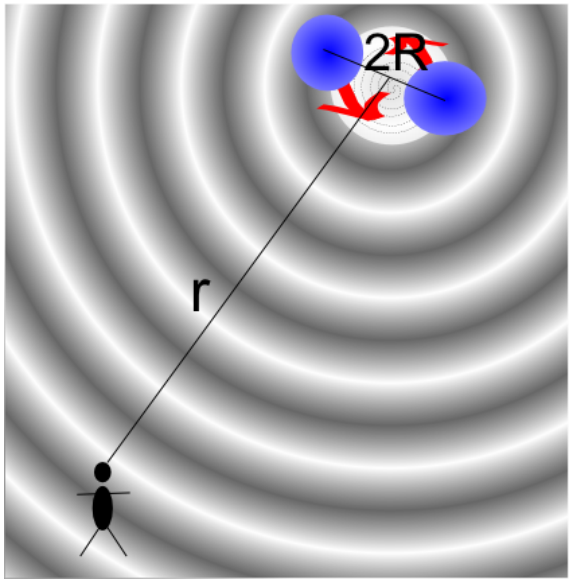
$$h \sim 10^{-21} \qquad (2)$$

Typical strain



$$M_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$h = 4\frac{G}{c^2}\frac{M_c}{r}\left(\frac{G}{c^3}\pi f M_c\right)^{2/3}$$

Assuming $m_1 = m_2 = m$ and recalling that

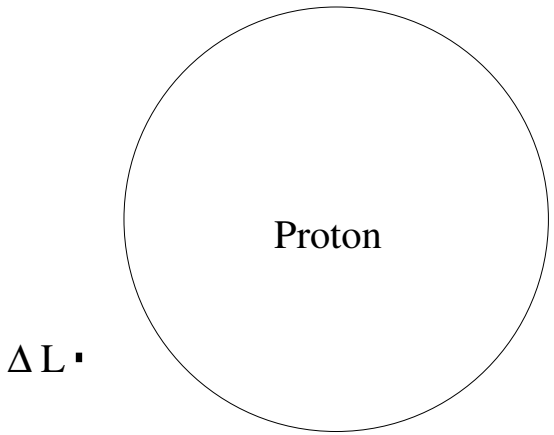
$$f^2 \sim Gm/R^3$$

we obtain

$$h \sim \frac{G^2 m^2}{rRc^4} \sim \frac{R_s^2}{Rr}$$

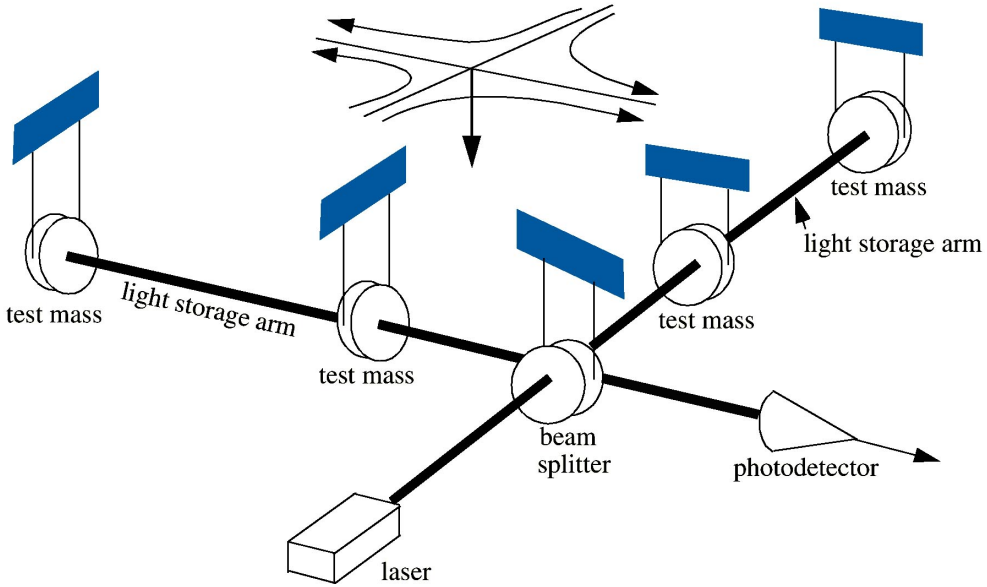
Where R_s is Schwarzschild radius of the mass m

$$R_s = \frac{2Gm}{c^2}$$

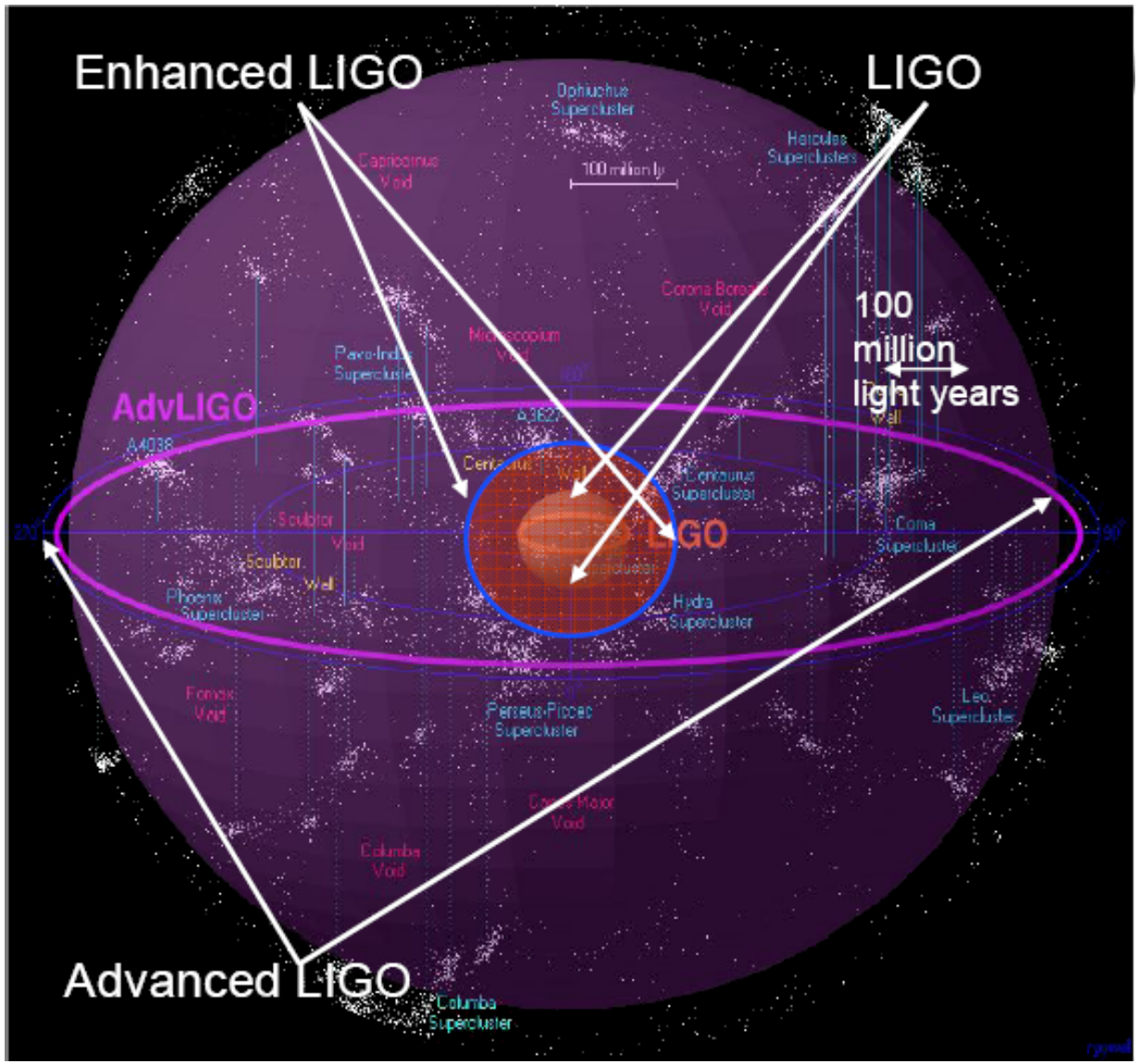


Laser Interferometer Gravitational-wave Observatory

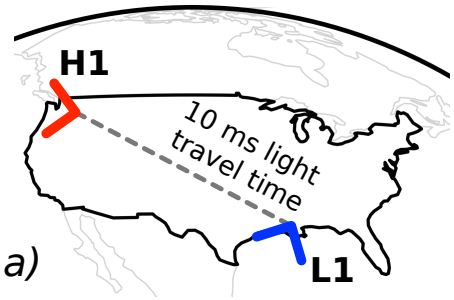
- $L = 4$ km
- $h \sim 10^{-23}$



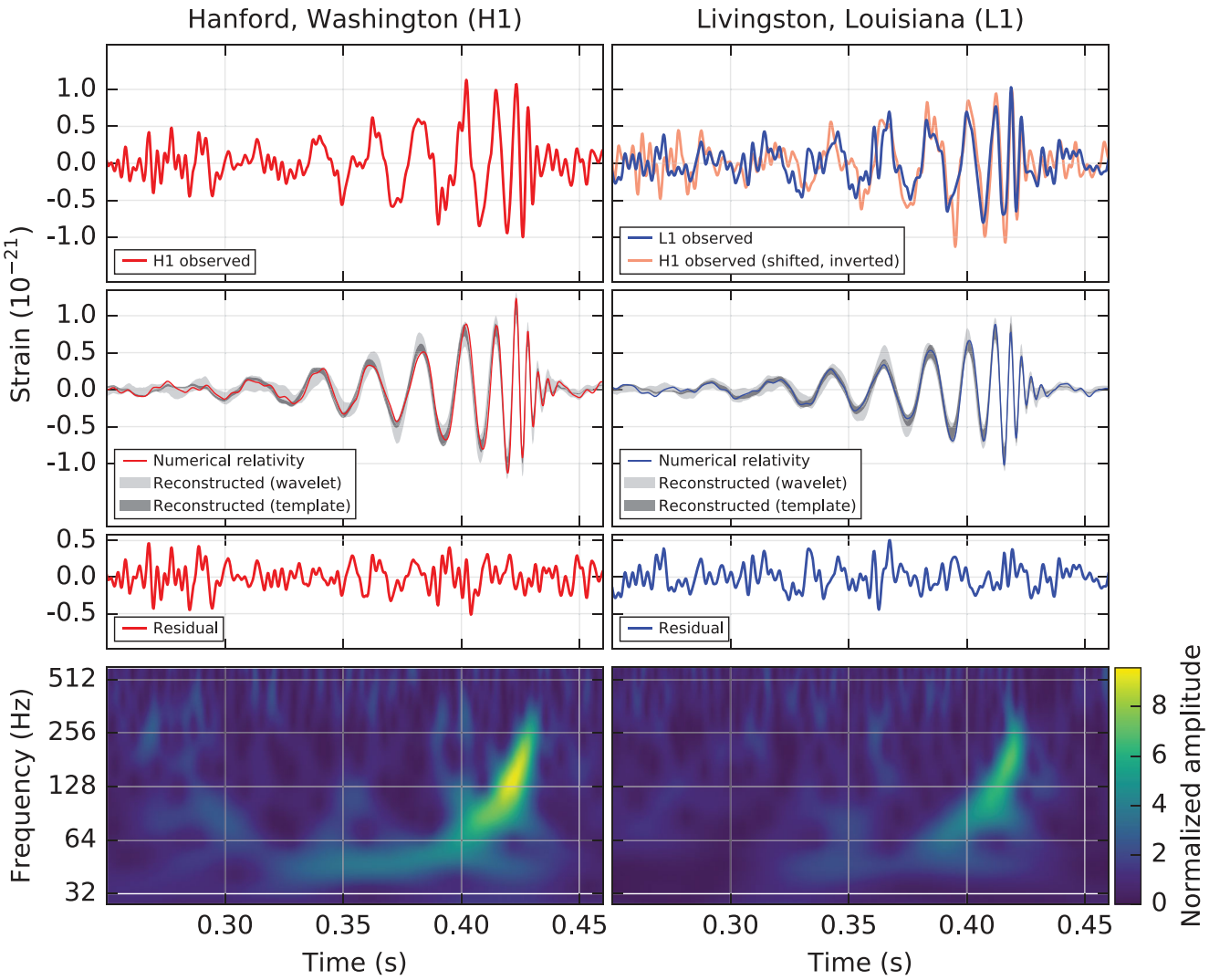
From LIGO to advanced LIGO



advanced LIGO detector summary



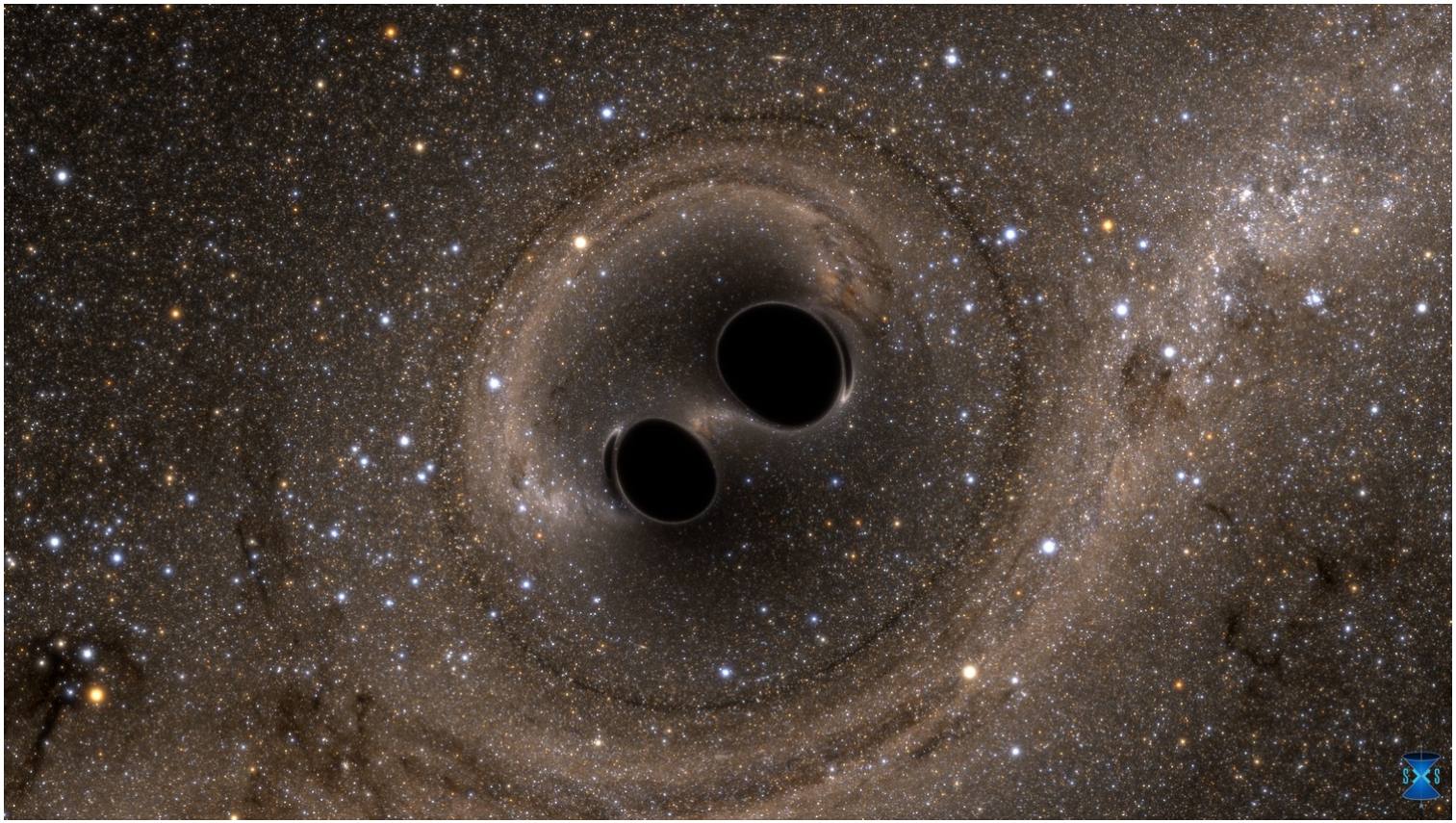
GW signal at 09:50:45 UTC on 14 September 2015



LIGO Scientific Collaboration, "Observation of Gravitational Waves from a Binary Black Hole Merger", Phys. Rev. Lett., 116, 061102, (2016).

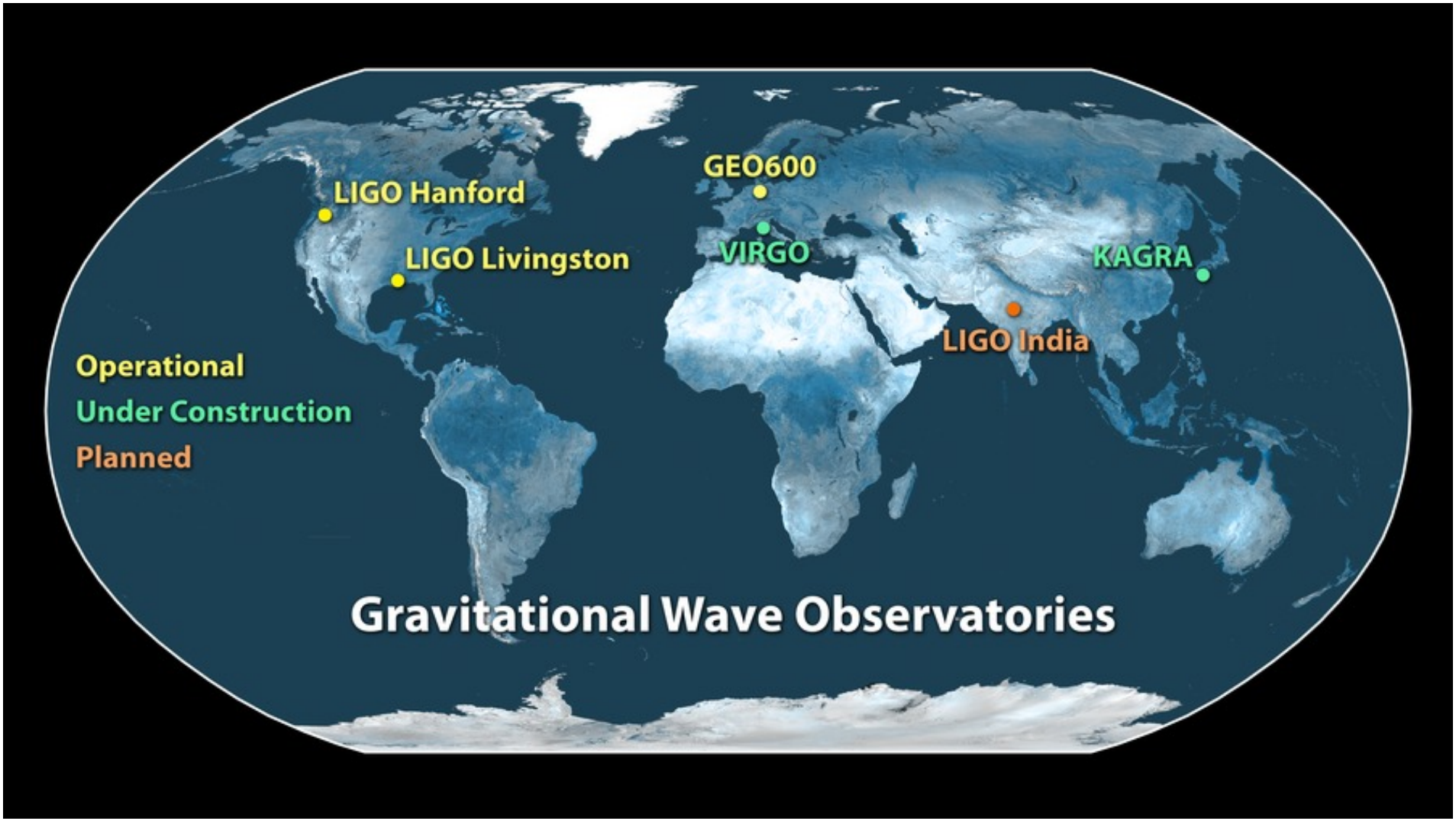
The sound of gravitational wave and simulated sky

- The Sound of Two Black Holes Colliding
- Two Black Holes Merge into One

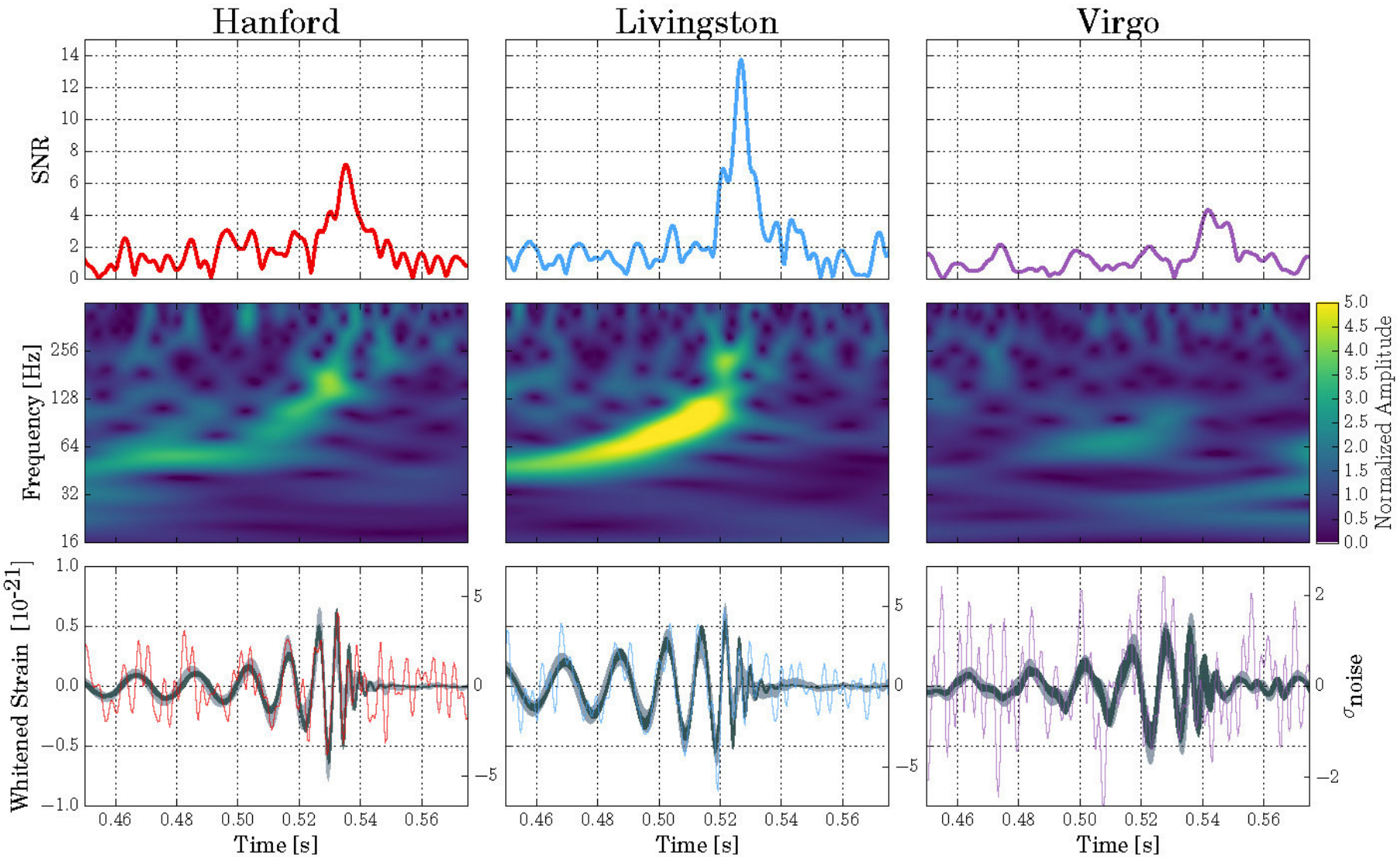


Two black holes with 29 and 36 solar masses merged about 1.3 billion years ago

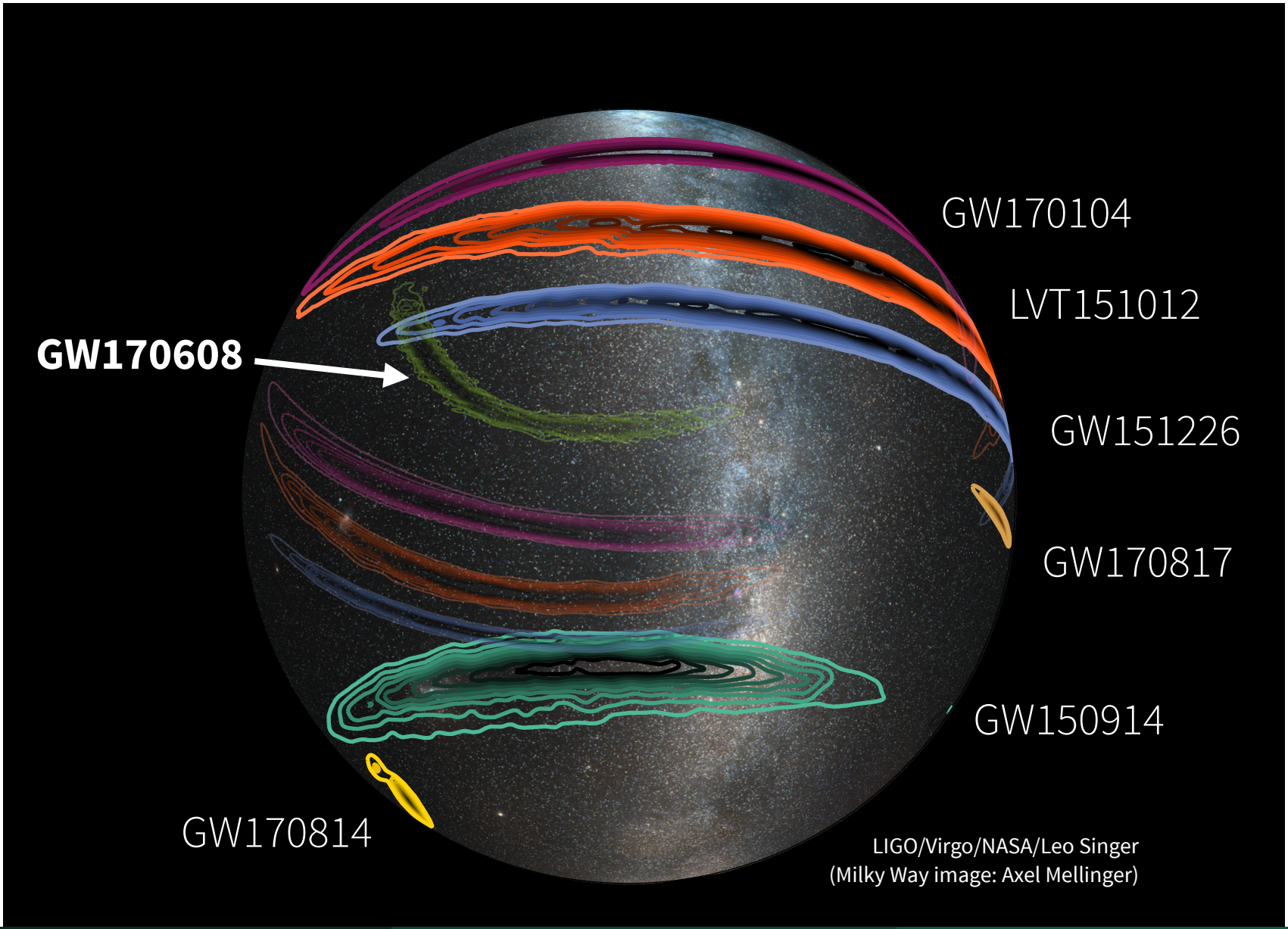
World wide network of detectors

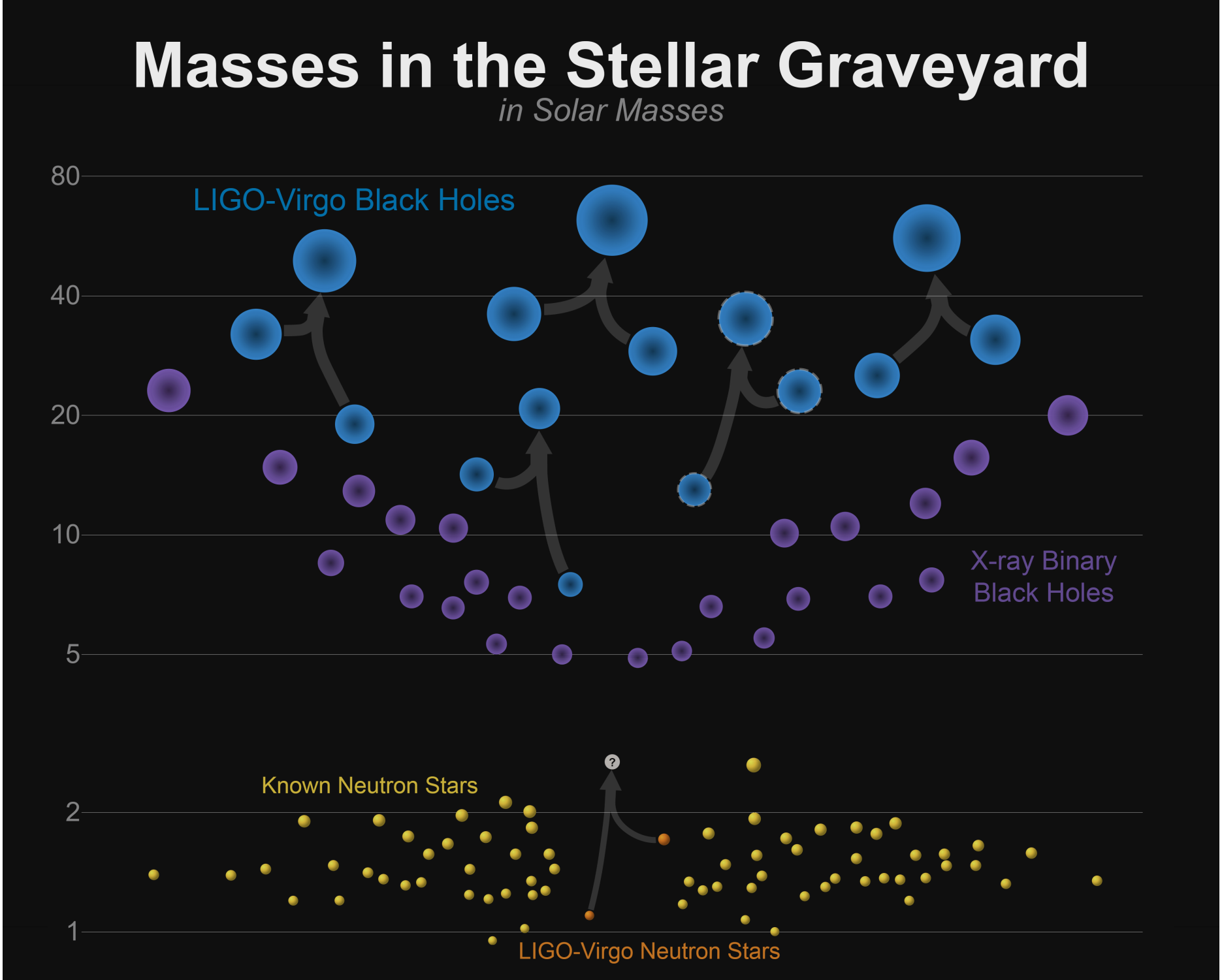


GW170814 triple detection

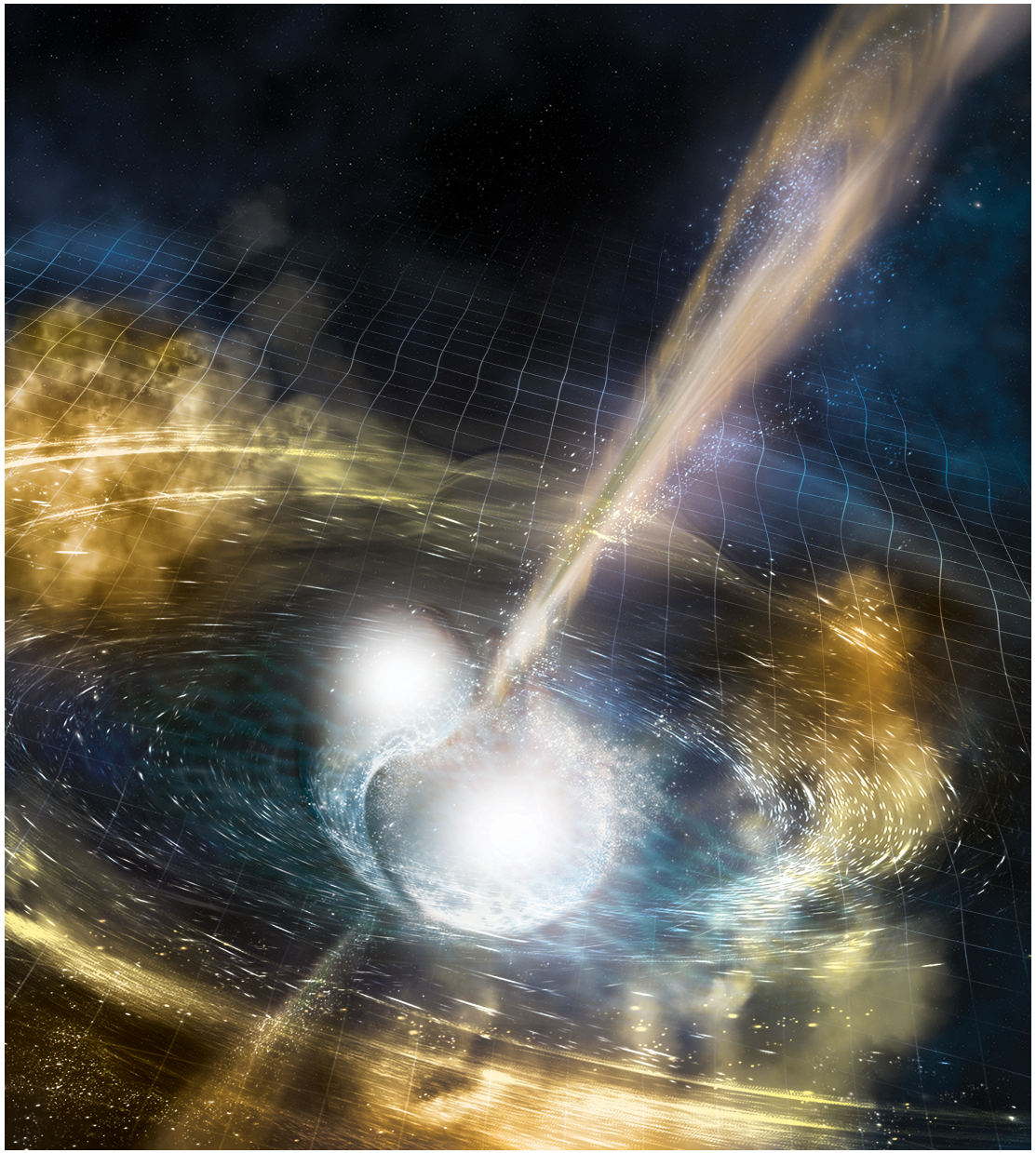


Sky maps


GW170104
LVT151012
GW170608
GW151226
GW170817
GW150914
GW170814
LIGO/Virgo/NASA/Leo Singer
(Milky Way image: Axel Mellinger)


Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
X-ray Binary
Black Holes
Known Neutron Stars
?
LIGO-Virgo Neutron Stars

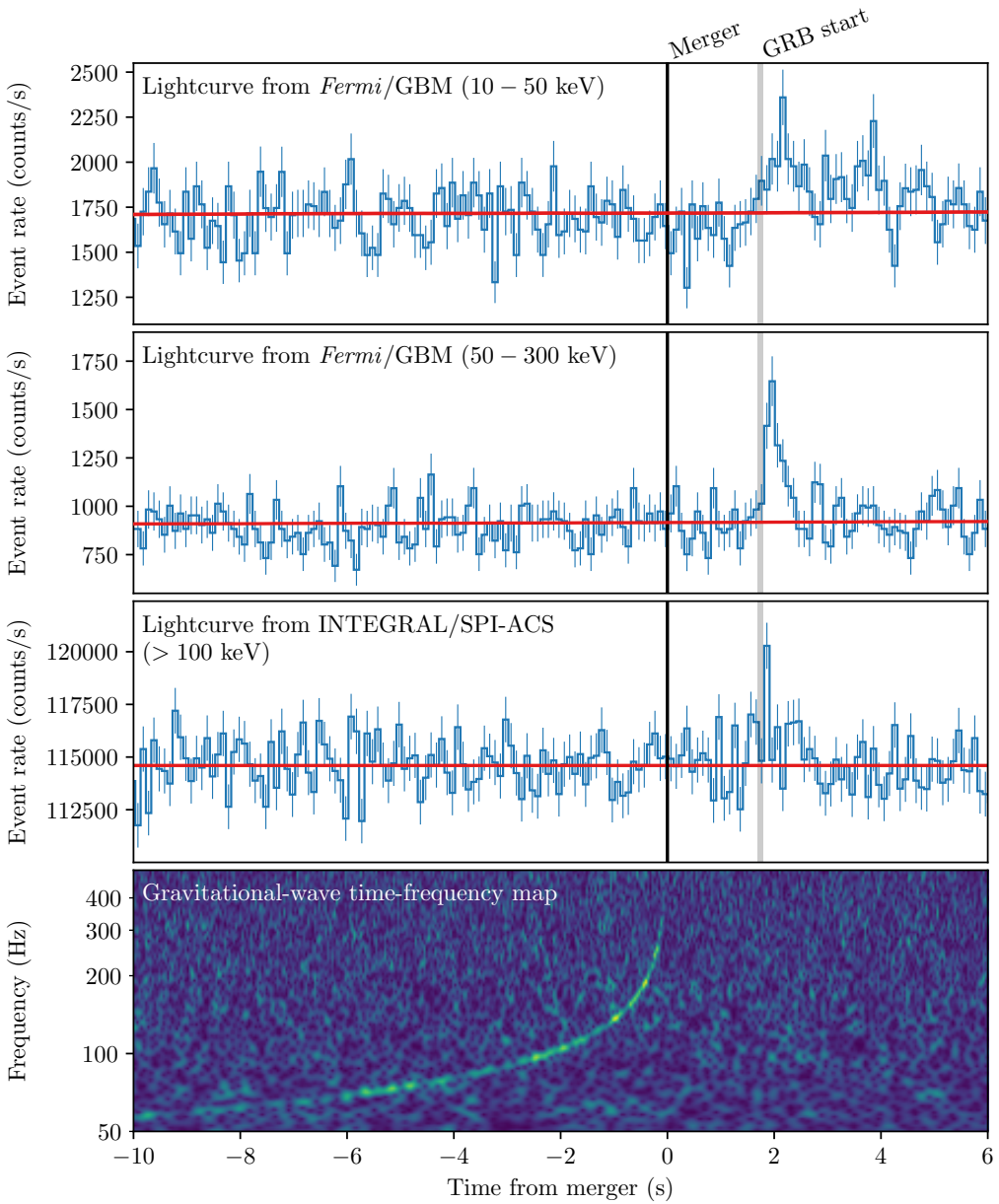
GW170817-kilonova artistic depiction



Simulation movie

https://youtu.be/V6cm-0bwJ98

GW170817-kilonova: two neutron stars collision



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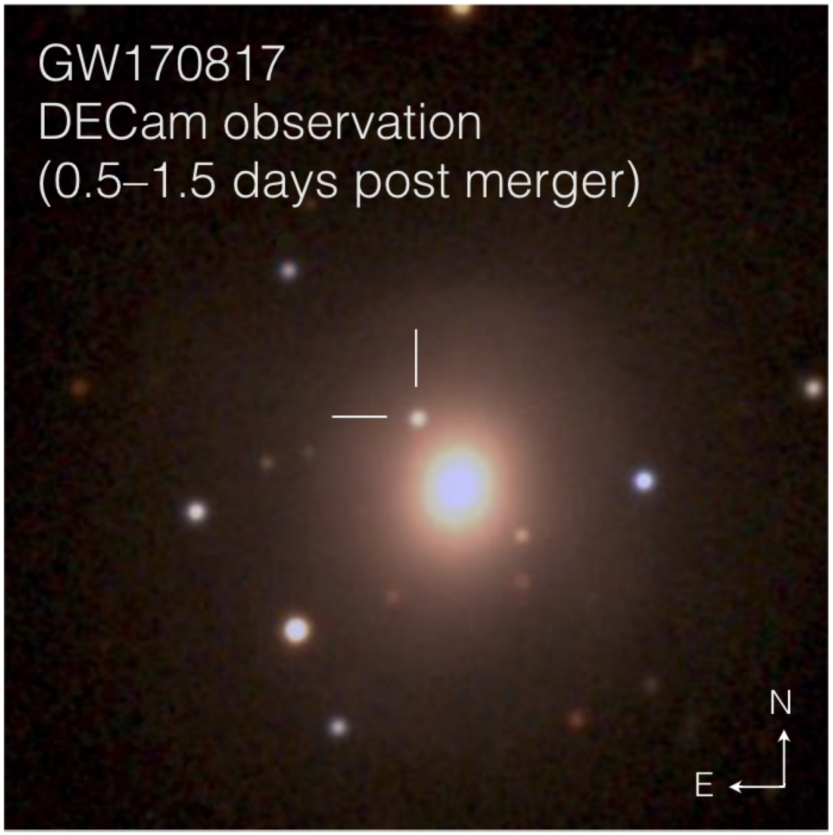
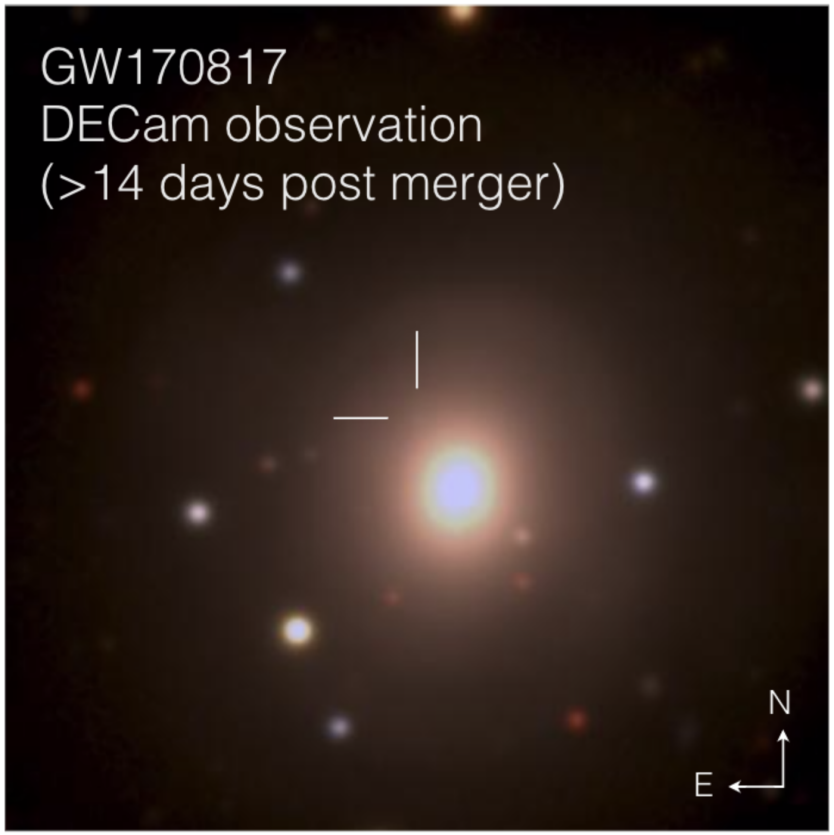
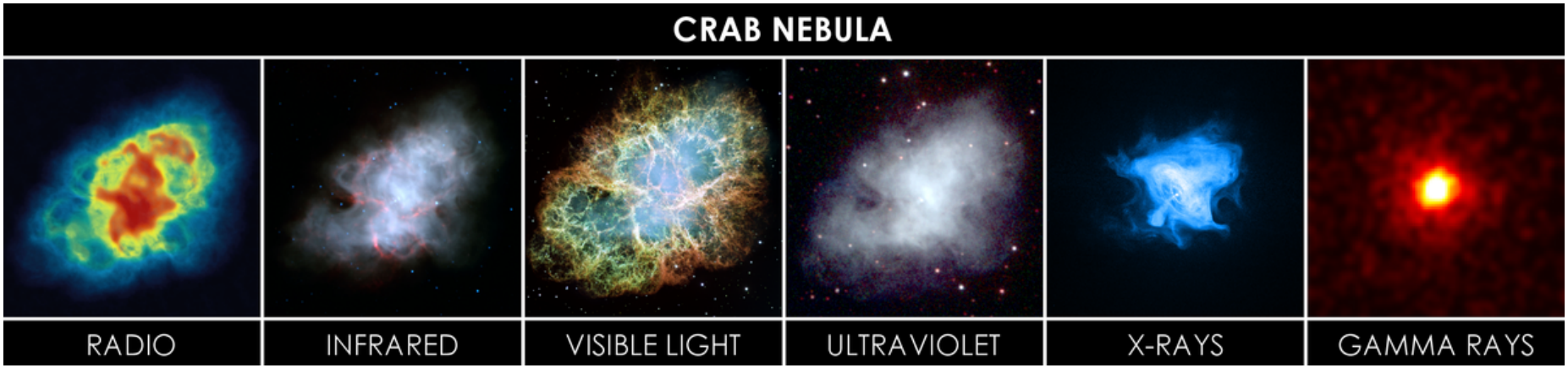


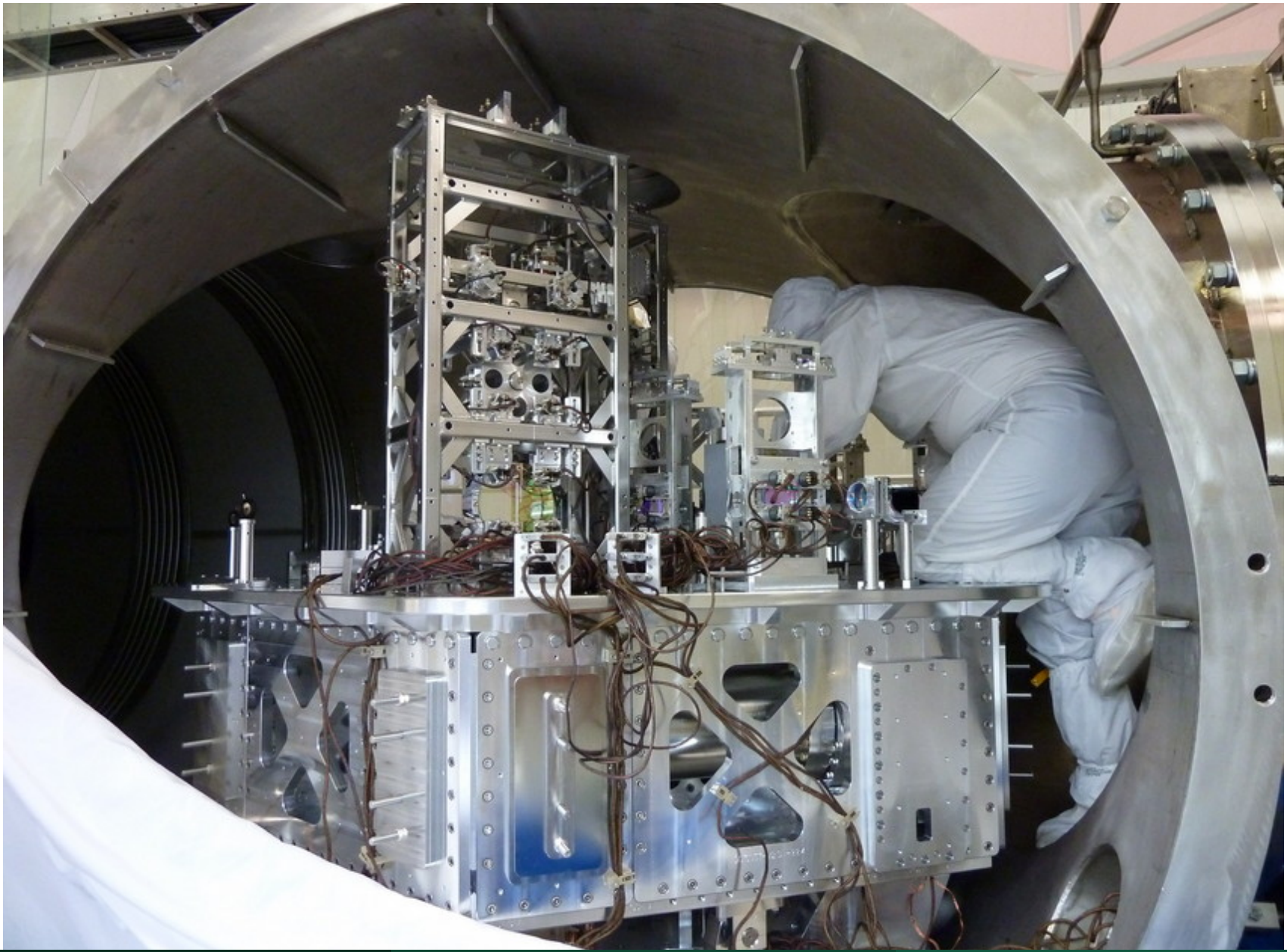


- GW170817: Coherent Spectrogram and Audio https://dcc.ligo.org/LIGO-G1701924
- GW170817: Fermi and LIGO signals https://wiki.ligo.org/pub/EPO/GW170817/GBM_GW170817_small.mov

Crab nebula, supernova 1054 remnants



Inside the tube



Seismic isolation

Photo from LIGO Magazine http://www.ligo.org/magazine/

Part of large system

Photo from LIGO Magazine http://www.ligo.org/magazine/

Work in chamber

Inside vacuum chamber

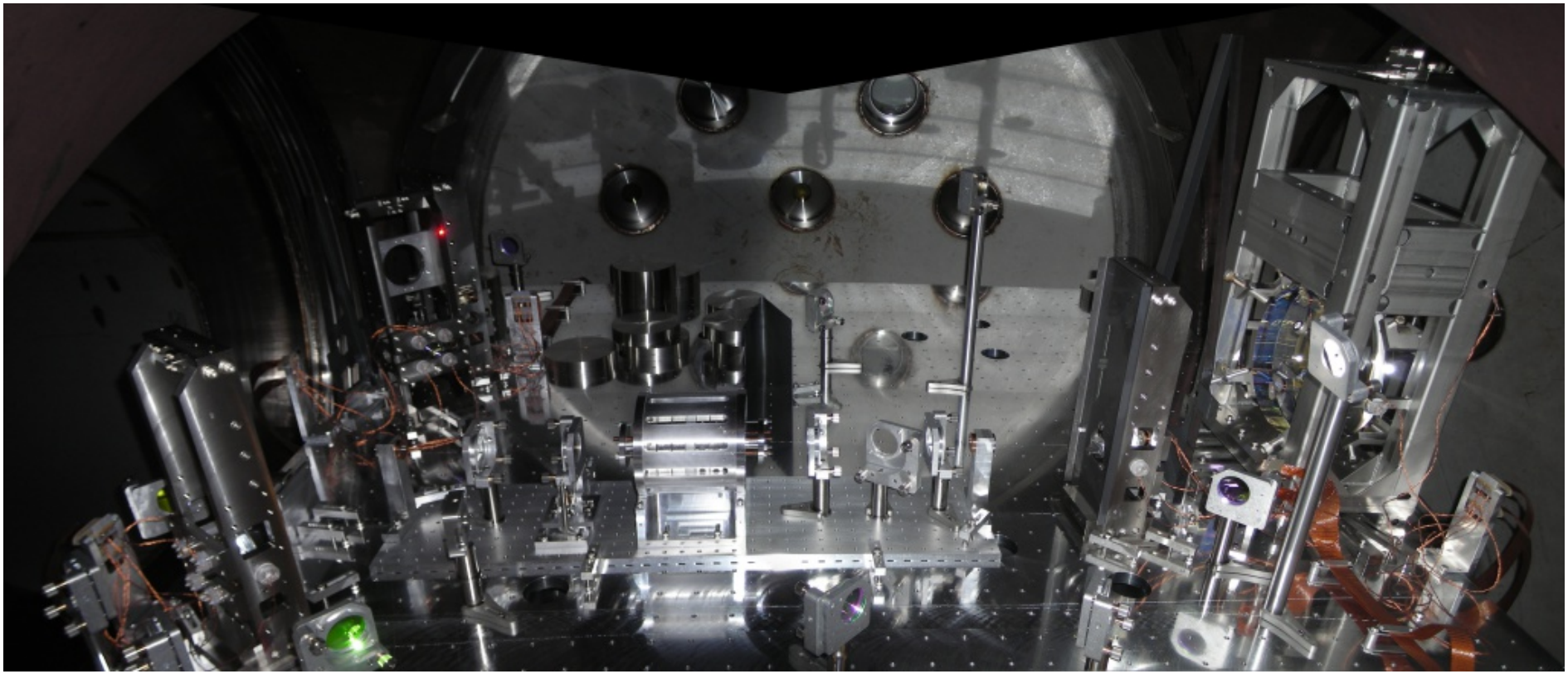
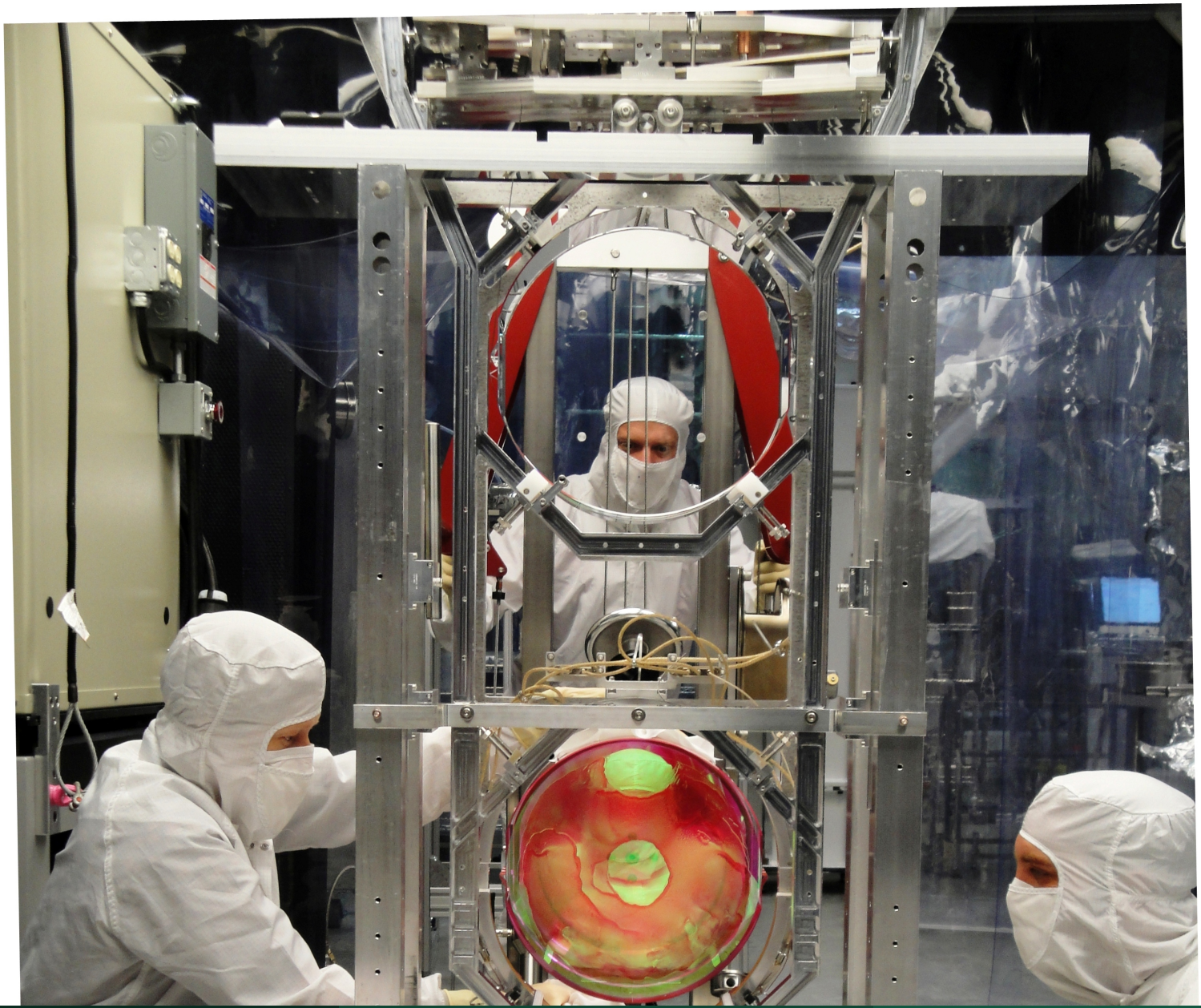


Photo from LIGO Magazine http://www.ligo.org/magazine/

Mode cleaner optics

Large optics suspension



Mirror

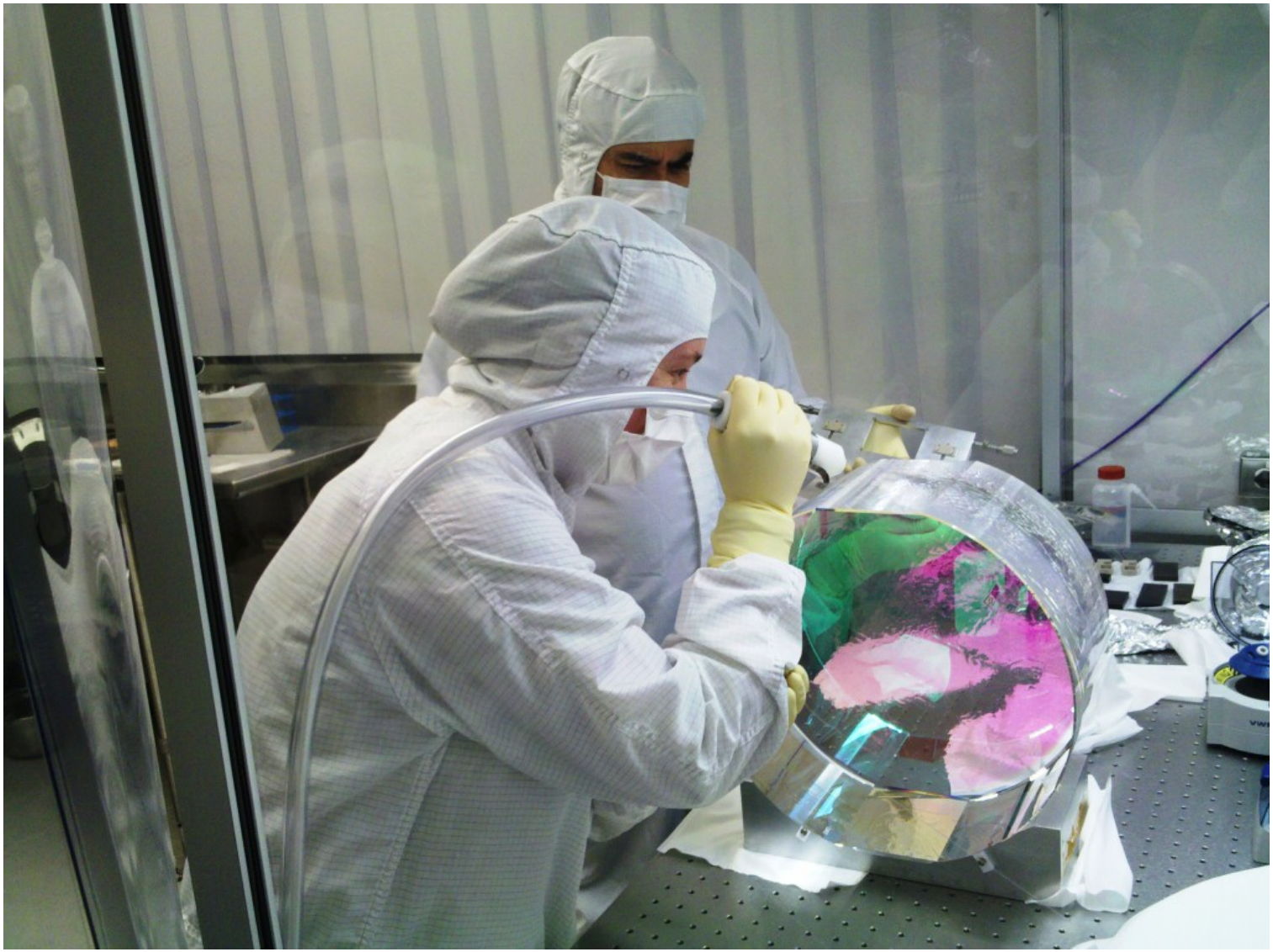


Photo from LIGO Magazine http://www.ligo.org/magazine/

Inner test mass

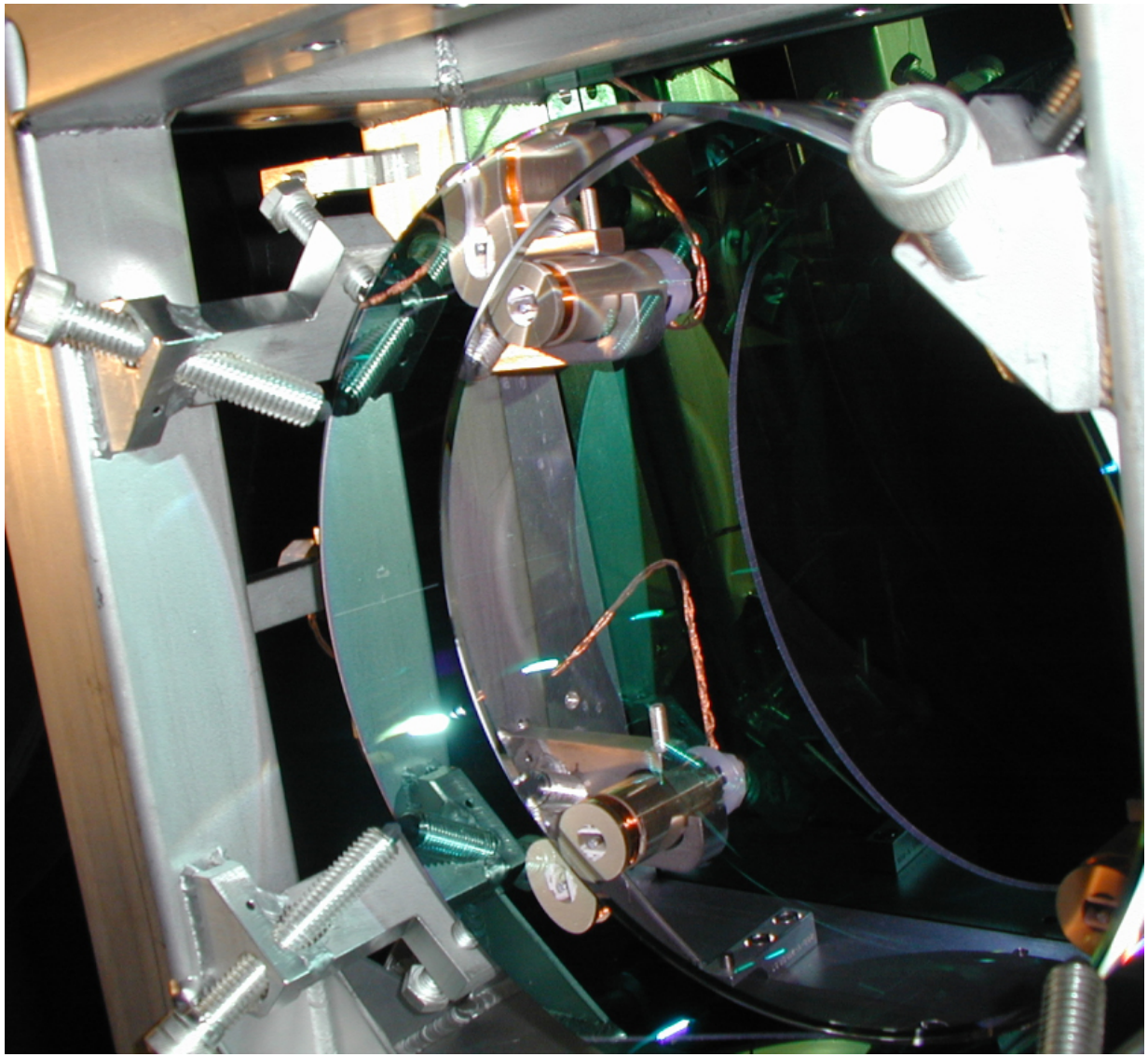
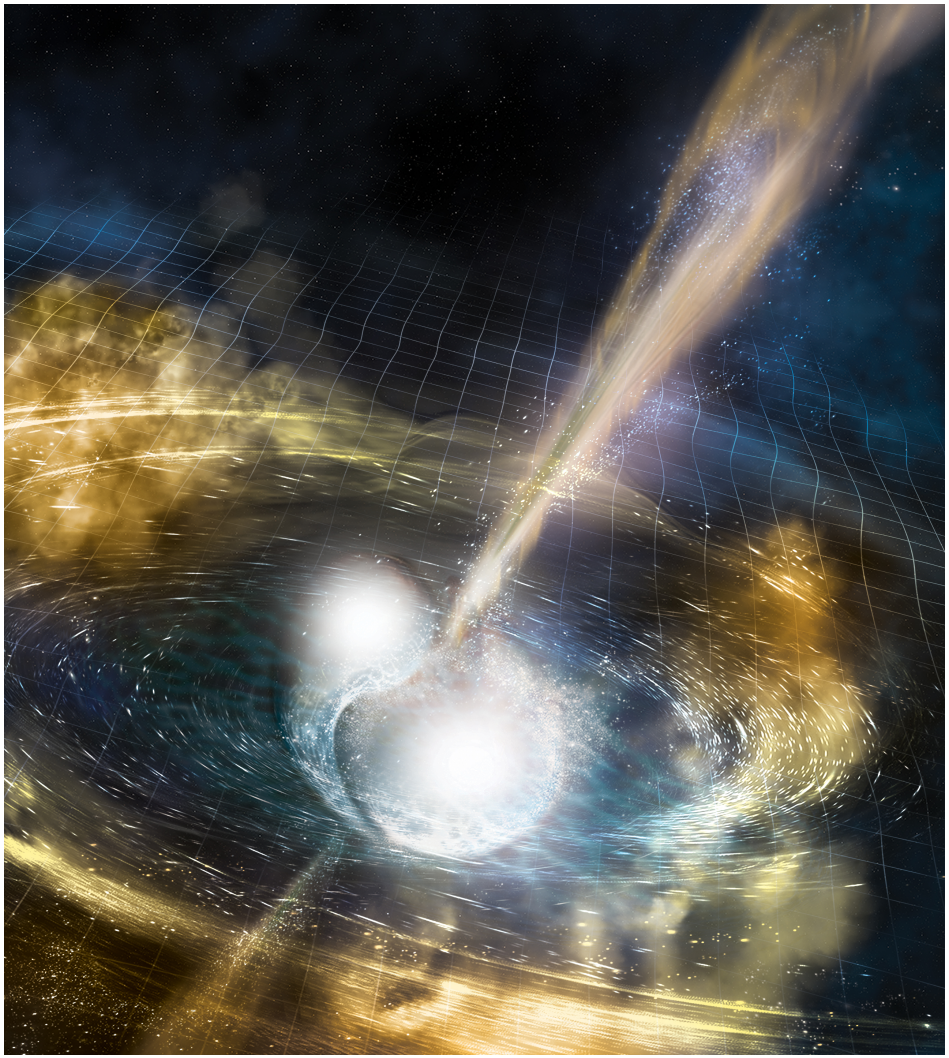


Photo from LIGO Magazine http://www.ligo.org/magazine/

We can detect stars collisions and ...

Summary



- In 2015 we detected the first Gravitational Wave
- Now we are talking about GW astronomy