

LIGO and discovery of the gravitational waves



and
Eugeniy E. Mikhailov



October 20th, 2017

2017/10/03 Nobel prize in Physics

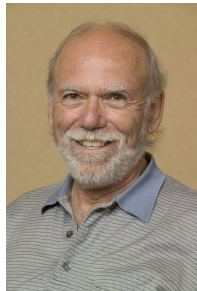
“for decisive contributions to the LIGO detector and the observation of gravitational waves”



Rainer Weiss



Kip S. Thorne



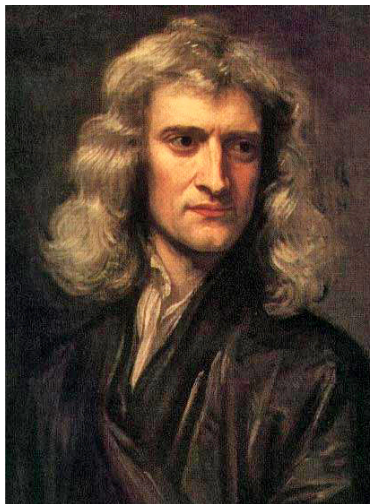
Barry C. Barish



LIGO Scientific Collaboration



Newton's laws 1686



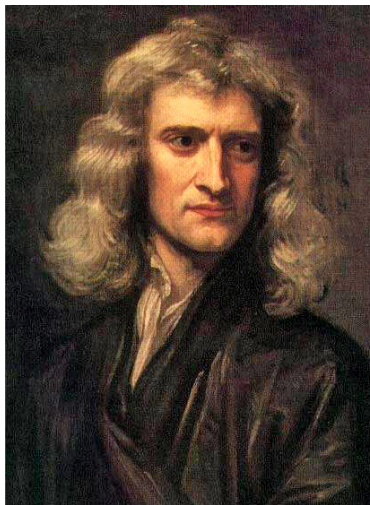
$$F_g = G \frac{m_1 m_2}{r^2}$$

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



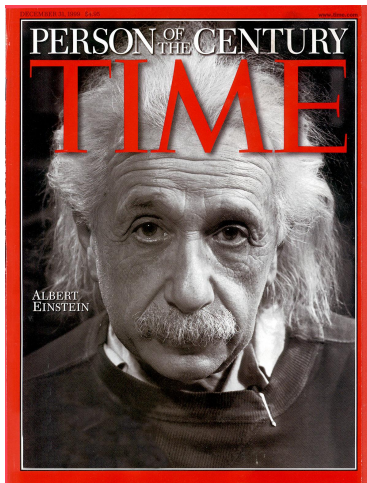
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Time is not in the formula

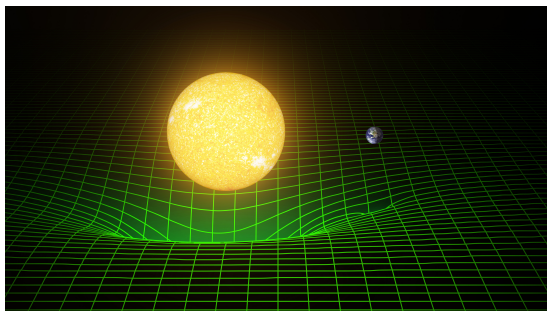


The General Theory of Relativity and theory of Gravity (1915)

- 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

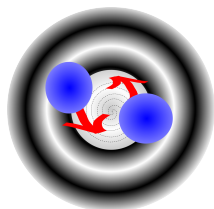


important predictions

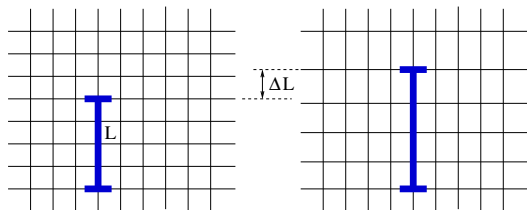
- Light path bends in vicinity of massive object → confirmed in 1919
- Gravitational radiation (waves) → confirmed **indirectly** in 1974

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

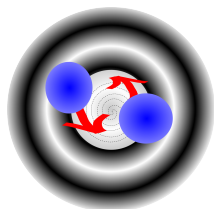
$$h = \frac{\Delta L}{L} \quad (1)$$

expected strain

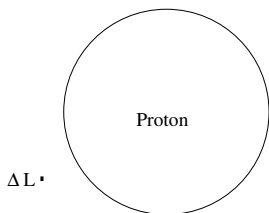
$$h \sim 10^{-21} \quad (2)$$

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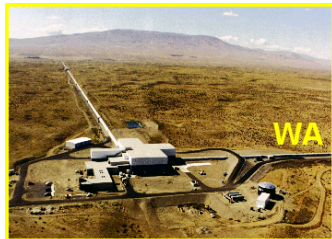
Strain - strength of GW

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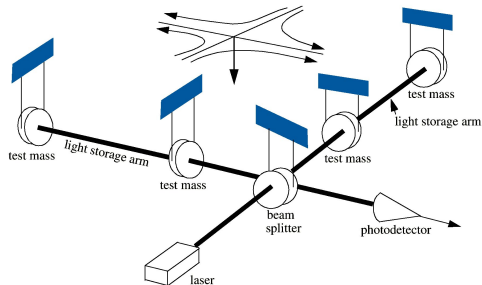
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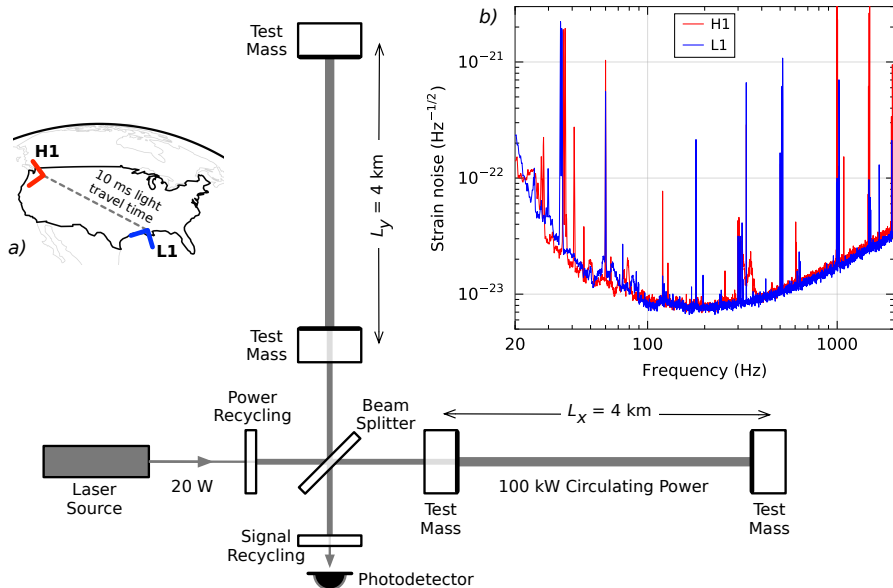
Laser Interferometer Gravitational-wave Observatory



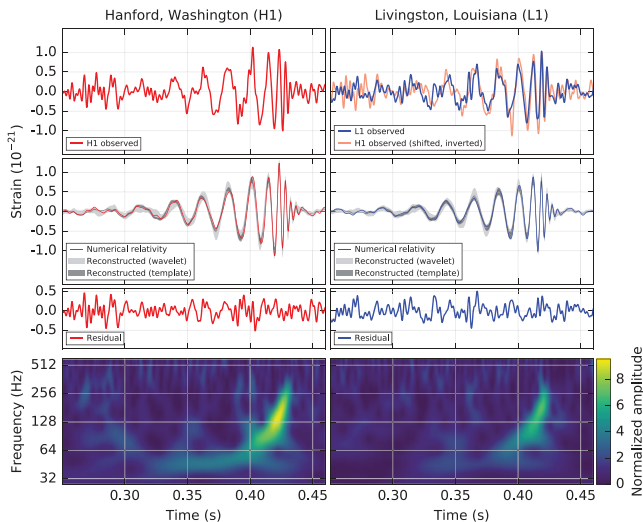
- $L = 4 \text{ km}$
- $h \sim 10^{-23}$



advanced LIGO detector summary



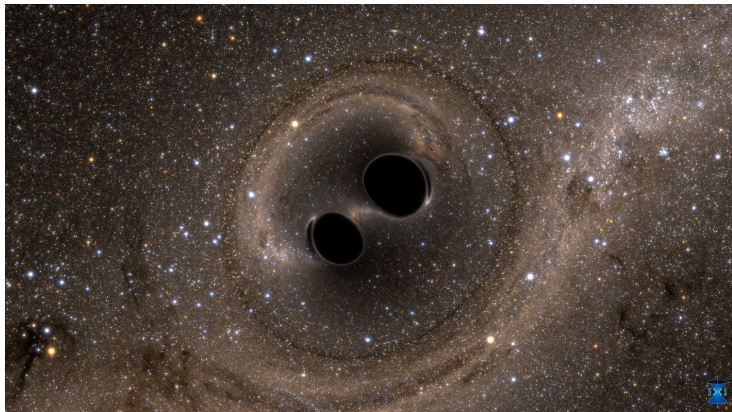
GW signal at 09:50:45 UTC on 14 September 2015



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

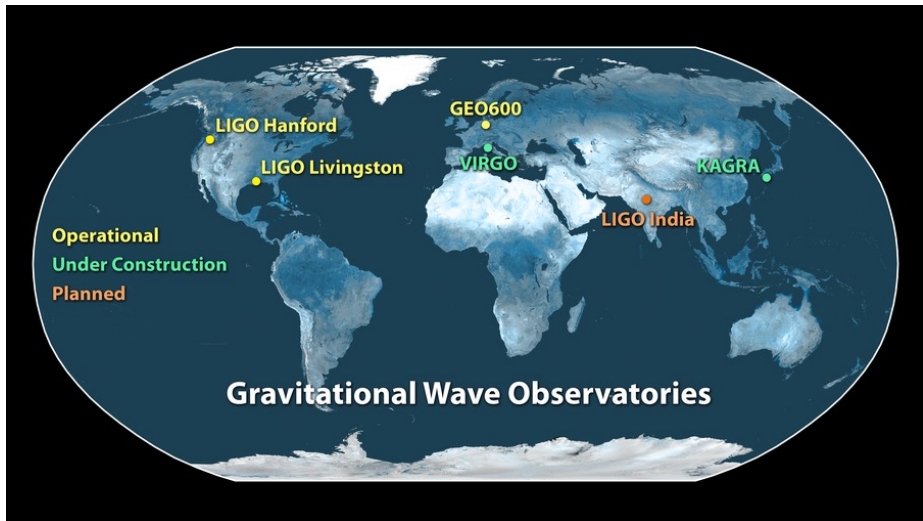
The sound of gravitational wave and simulated sky

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

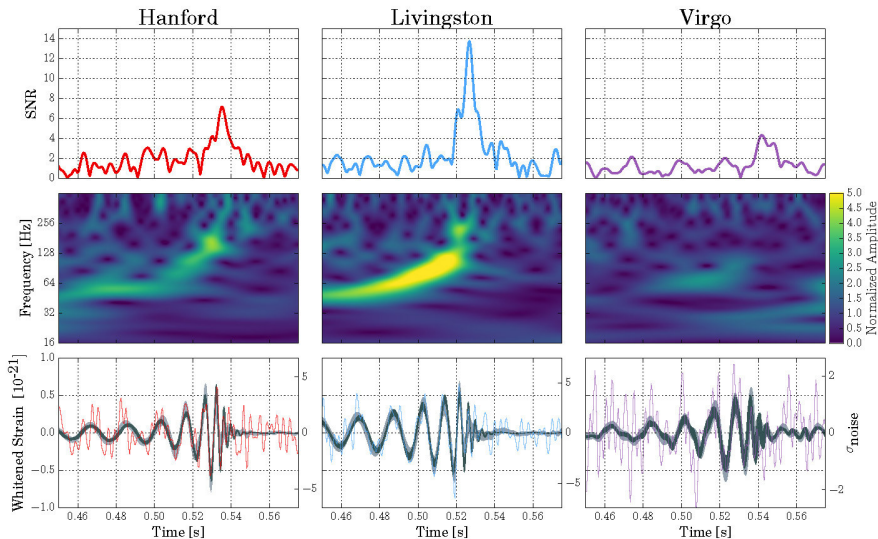


Two black holes with 29 and 36 solar masses merged about 1.3 billion years ago

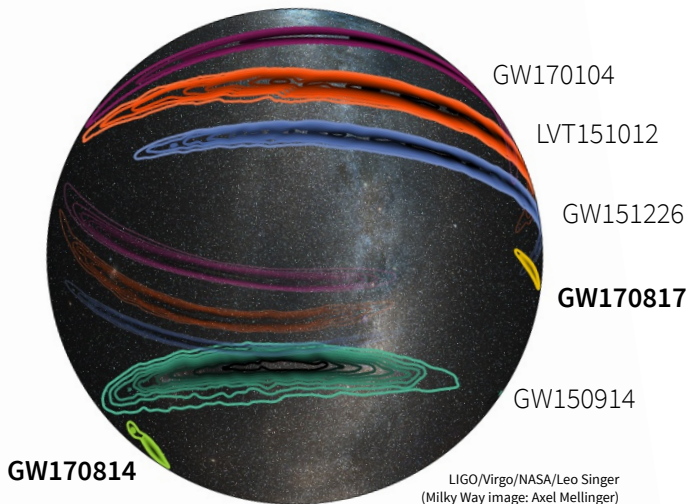
World wide network of detectors



GW170814 triple detection

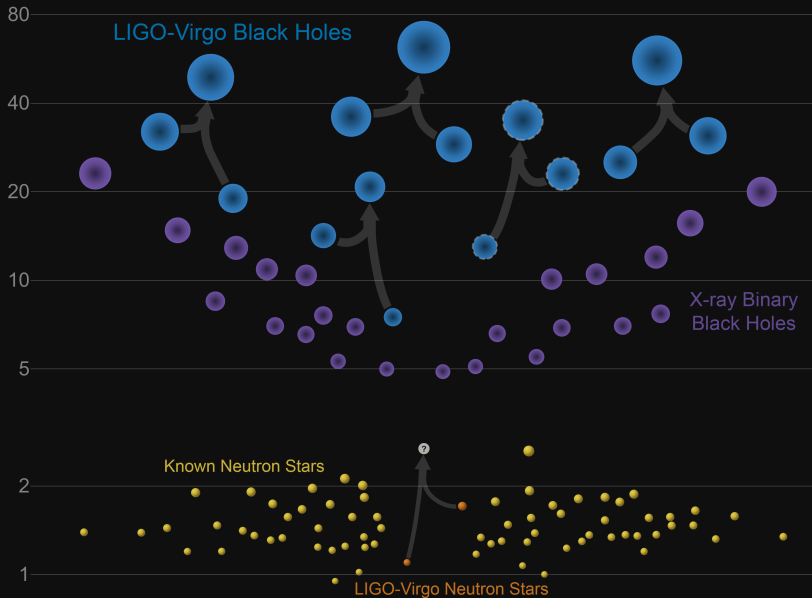


Sky maps

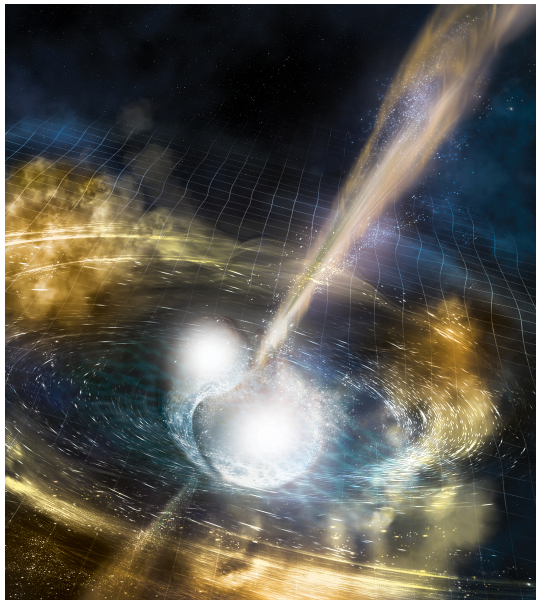


Masses in the Stellar Graveyard

in Solar Masses

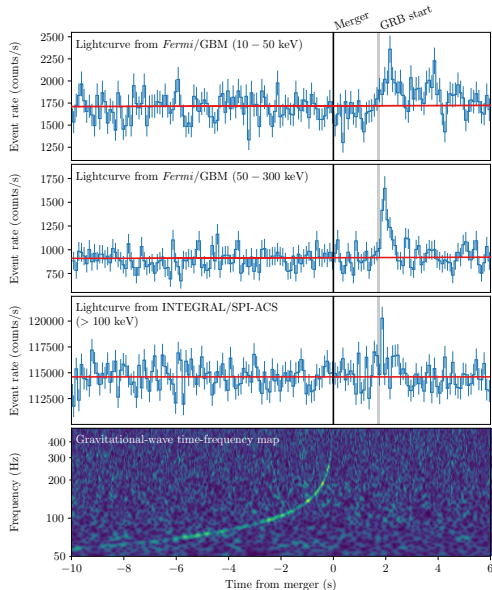


GW170817-kilonova artistic depiction

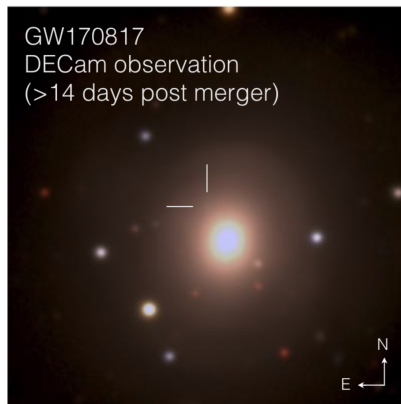
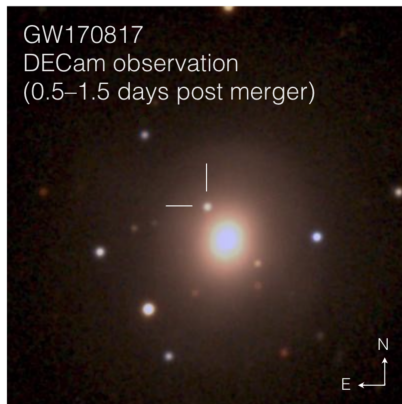


Simulation movie
<https://youtu.be/V6cm-0bwJ98>

GW170817-kilonova: two neutron stars collision

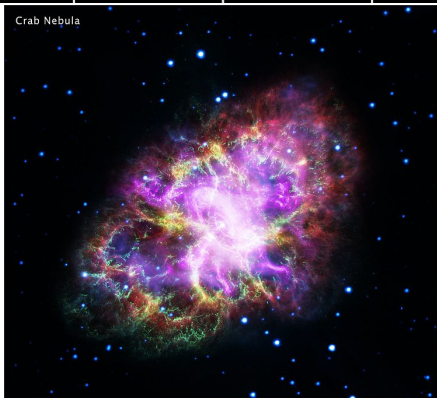
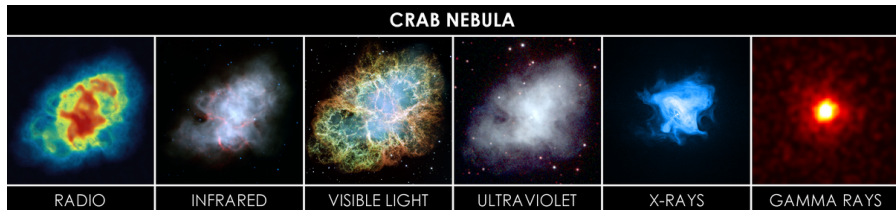


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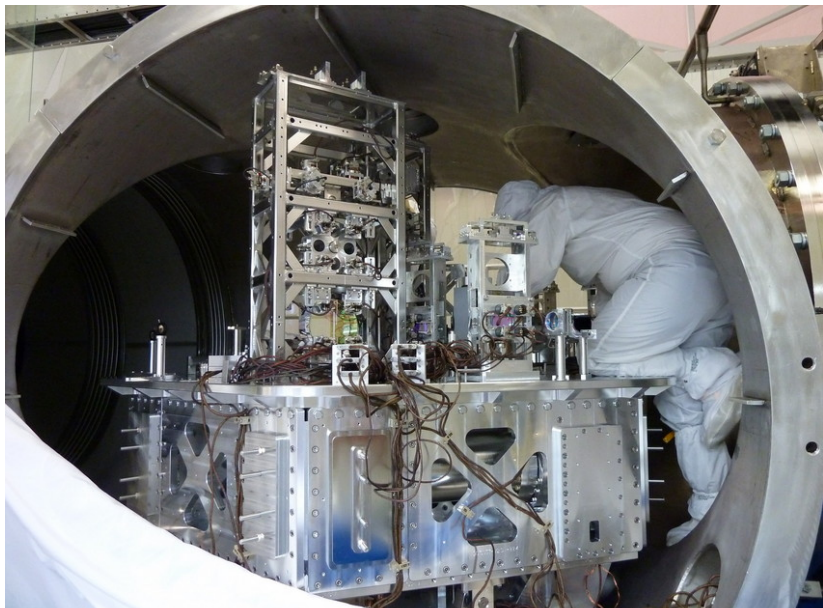


- GW170817: Coherent Spectrogram and Audio <https://dcc.ligo.org/LIGO-G1701924>
- GW170817: Fermi and LIGO signals https://wiki.ligo.org/pub/EPO/GW170817/GBM_GW170817_small.mov

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

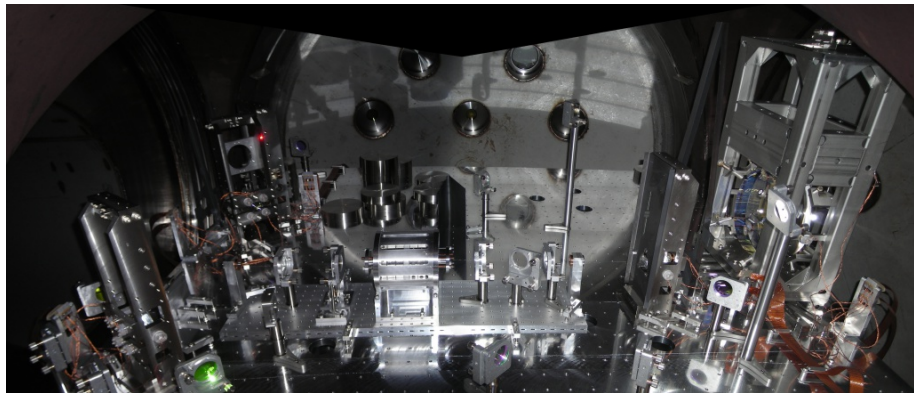
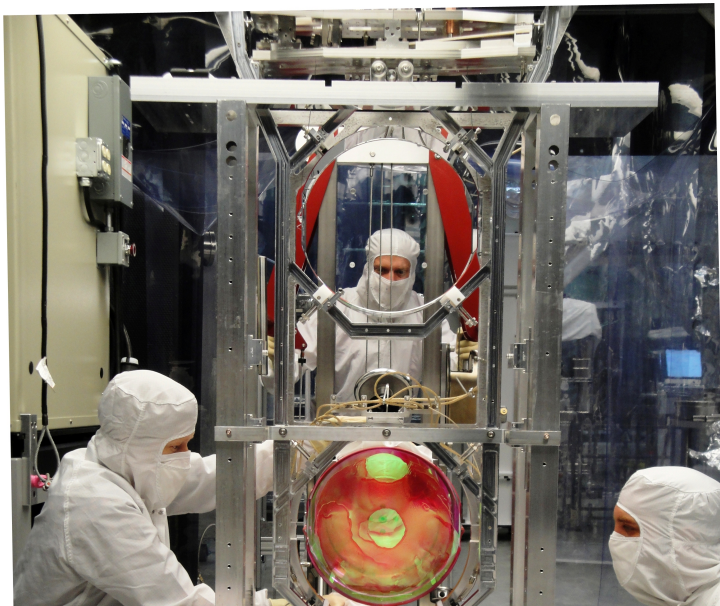


Photo from LIGO Magazine <http://www.ligo.org/magazine/>

Mode cleaner optics



Large optics suspension



Mirror

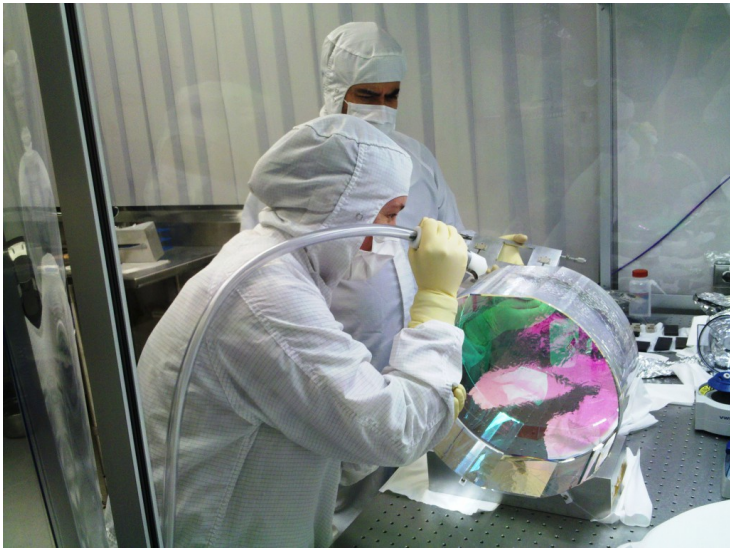


Photo from LIGO Magazine <http://www.ligo.org/magazine/>

Inner test mass

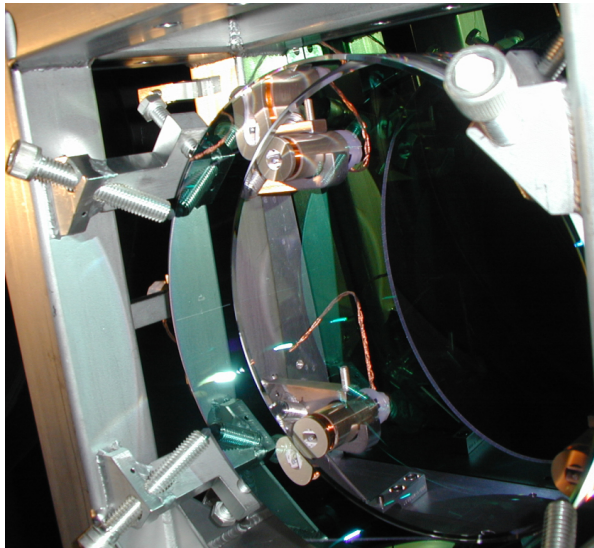
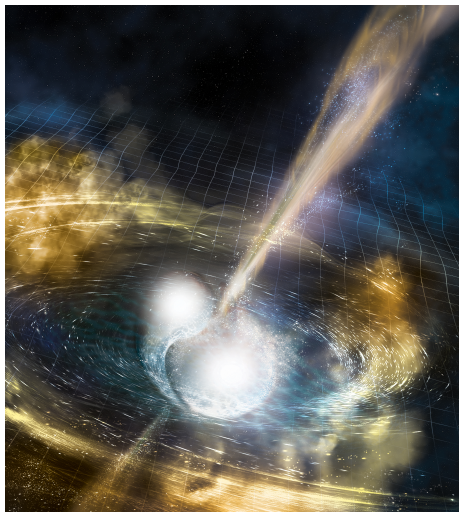


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We can detect stars collisions and ...



Summary



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