

LIGO - Recent results

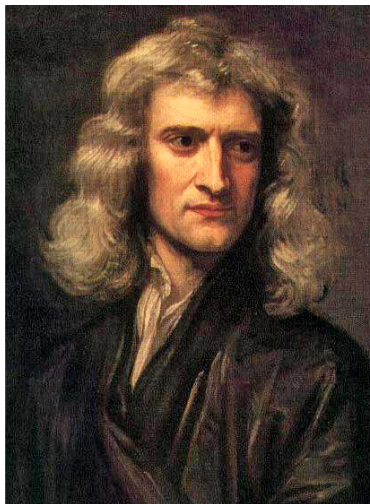


and
Eugeniy E. Mikhailov



March 12, 2016

- 1 History of gravity
 - Newton's laws
 - Einstein's laws
 - A bit of astrophysics
- 2 Detectors
 - Gravitational wave interferometer
- 3 Detection
- 4 Assorted LIGO pictures
 - Extra information



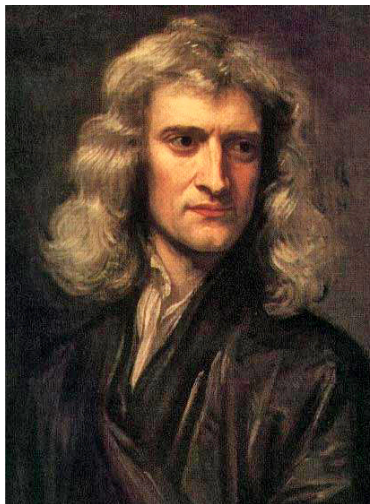
$$F_g = G \frac{m_1 m_2}{r^2}$$

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.

Did not explained precession of Mercury orbit



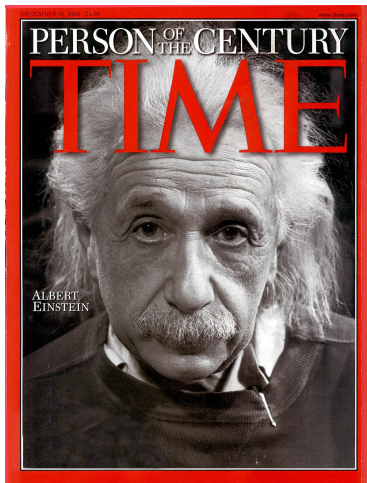
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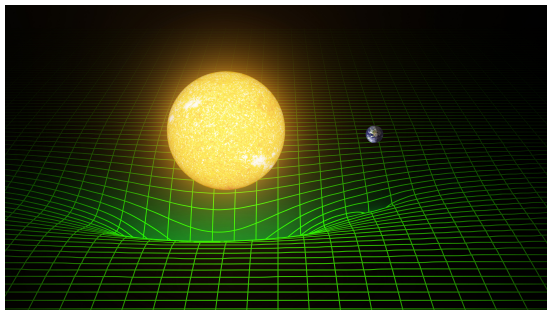


The General Theory of Relativity and theory of Gravity (1915)

- 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



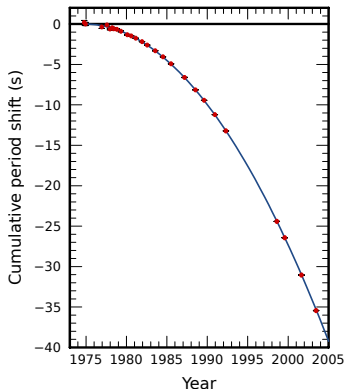
Indirect observation of gravitational wave

Emission of gravitational radiation from pulsar PSR1913+16 leads to loss of orbital energy.

- orbital period decreased by 36 sec from 1975 to 2005
- measured to 50 ms accuracy
- deviation grows quadratically with time

This can be explained by general relativistic effects: J.H. Taylor and J.M. Weisberg, *Astrophysical Journal*, Part 1, vol. 253, Feb. 15, 1982, p. 908-920.

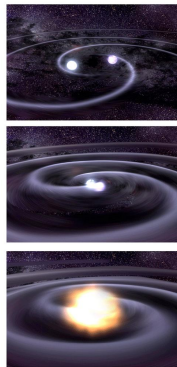
Nobel prize in 1993 to Hulse and Taylor



Astrophysical sources of GW

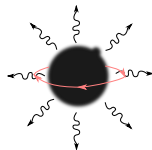
- Coalescing compact binaries

- objects: NS-NS, BH-NS, BH-BH
- physics regimes: Inspiral, merger, ringdown



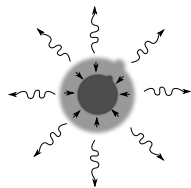
- Periodic sources

- spinning neutron stars (pulsars)

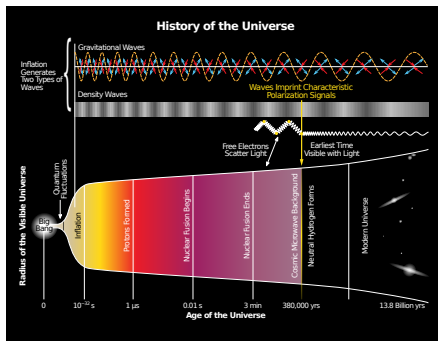


Astrophysical sources of GW (cont)

- Burst events
 - Supernovae with asymmetric collapse



- Stochastic background
 - right after Big Bang ($t = 10^{-43}$ sec)
 - continuum of sources



Astrophysics with GWs vs. E&M

E&M (photons)

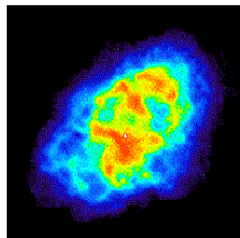
- Space as medium for field
- Accelerating charge
- Absorbed, scattered, dispersed by matter
- 10 MHz and up
- Light = not dark (but >95% of Universe is dark)

GW

- Spacetime itself ripples
- Accelerating aspherical mass
- Very small interaction; matter is transparent
- 10 kHz and down
- Radiated by dark mass distributions

New view to the universe

Crab Nebula: Remnant of an Exploded Star (Supernova)



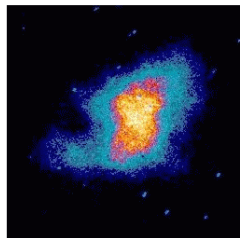
Radio wave (VLA)



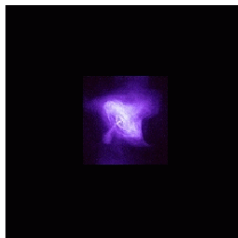
Infrared radiation (Spitzer)



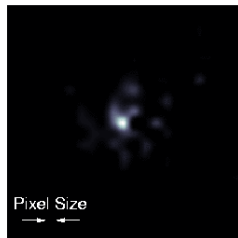
Visible light (Hubble)



Ultraviolet radiation (Astro-1)



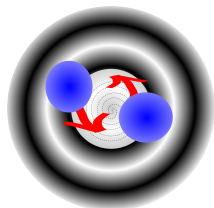
Low-energy X-ray (Chandra)



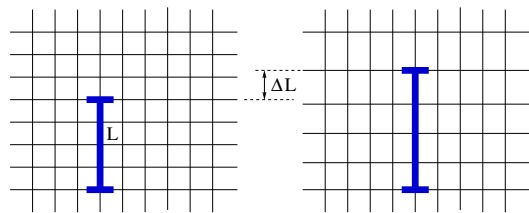
High-energy X-ray (HEFT)

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
- New tool for astrophysics



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



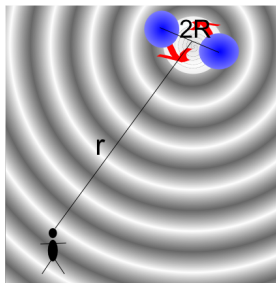
Strain - strength of GW

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

typical strain

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

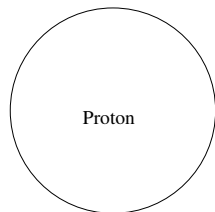
Typical strain



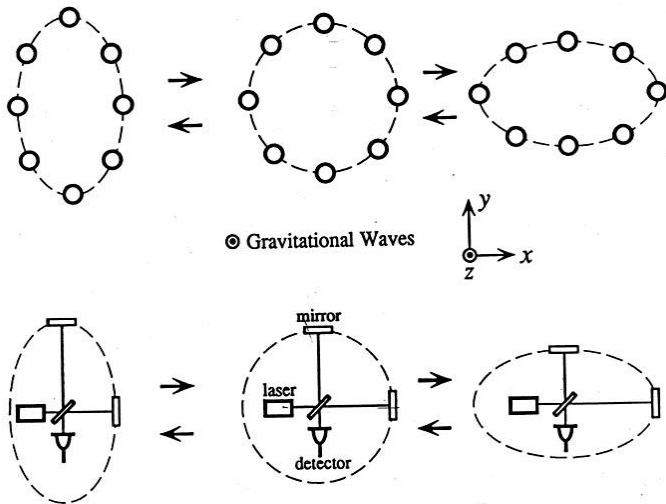
Two neutron star

with a mass of 1.4 solar masses each
orbiting each other with a frequency $f = 400$ Hz
at a distance $2R = 20$ km
would generate strain $h \sim 10^{-21}$
at distance equal to 10^{23} m
(distance to the Virgo cluster)
For 4 km base line that would correspond to
 ΔL thousand times smaller than size of proton.

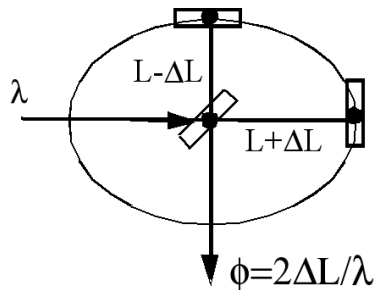
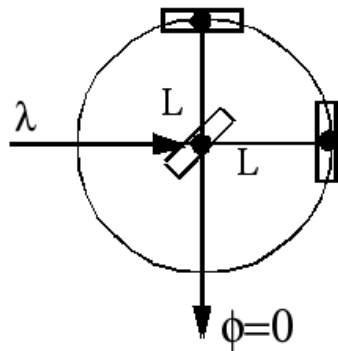
Detection of GW is difficult problem



GW acting on matter



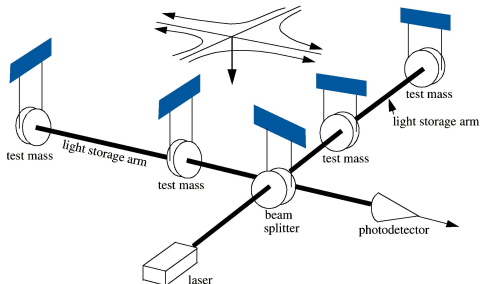
Interferometric Measurement



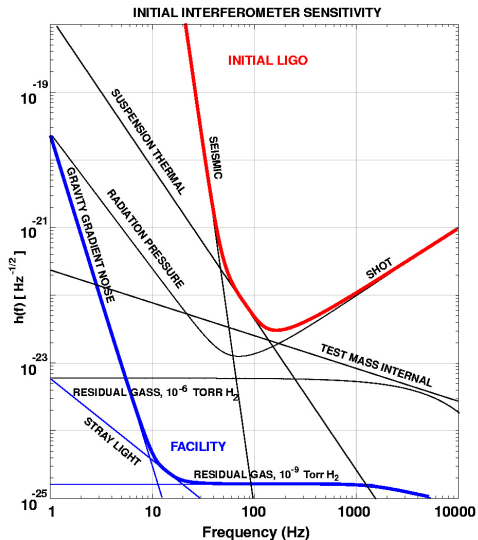
Laser Interferometer Gravitational-wave Observatory



- $L = 4 \text{ km}$
- $h \sim 2 \times 10^{-23}$
- $\Delta L \sim 10^{-20} \text{ m}$



Initial LIGO sensitivity goal and noise budget



Displacement noise

- seismic
- thermal suspension
- thermal Brownian
- radiation pressure noise

Detection noise

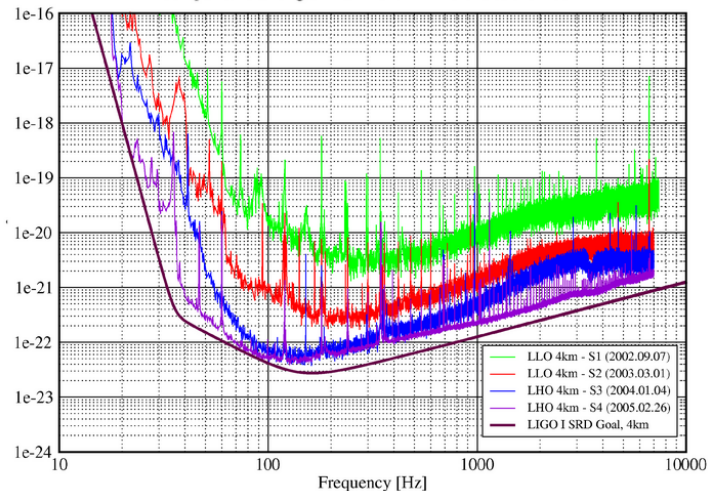
- electronics
- shot noise

LIGO sensitivity, S1-S4 runs

Best Strain Sensivities for the LIGO Interferometers

Comparisons among S1 - S4 Runs

LIGO-G050482-00-Z

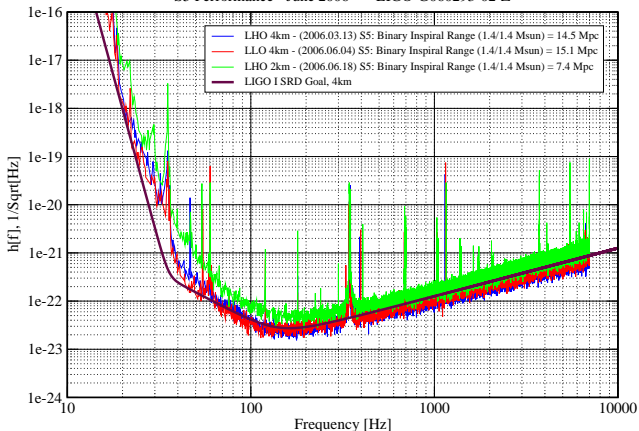


Inspiral search range during S4 was 8Mpc

LIGO sensitivity, S5 run, June 2006

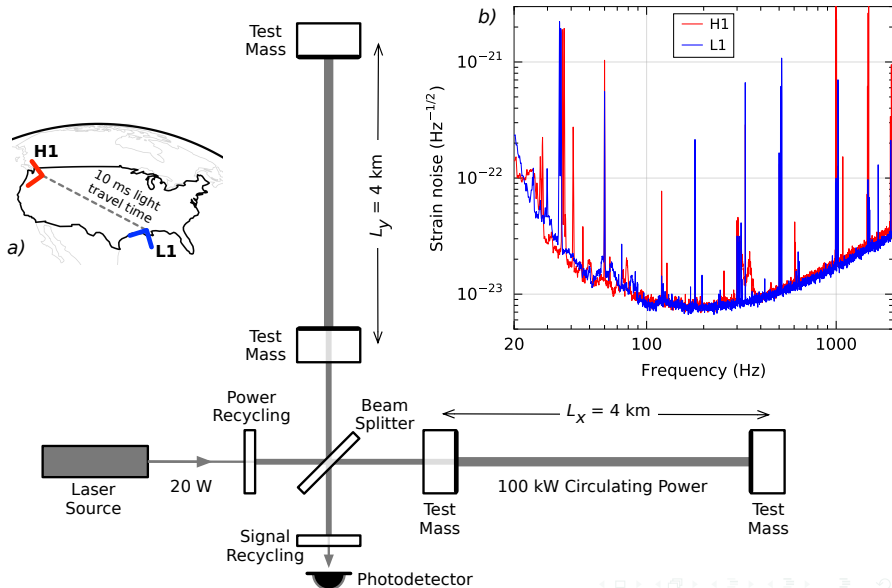
Strain Sensitivity for the LIGO Interferometers

S5 Performance - June 2006 LIGO-G060293-02-Z

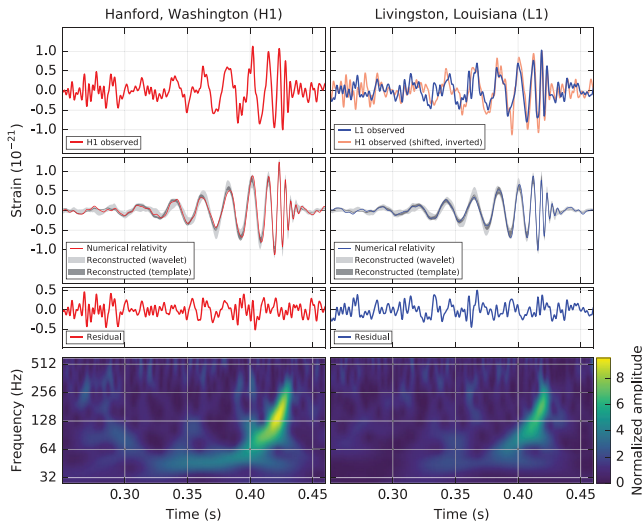


Inspirational search range during S5 is 14Mpc

LIGO detector summary



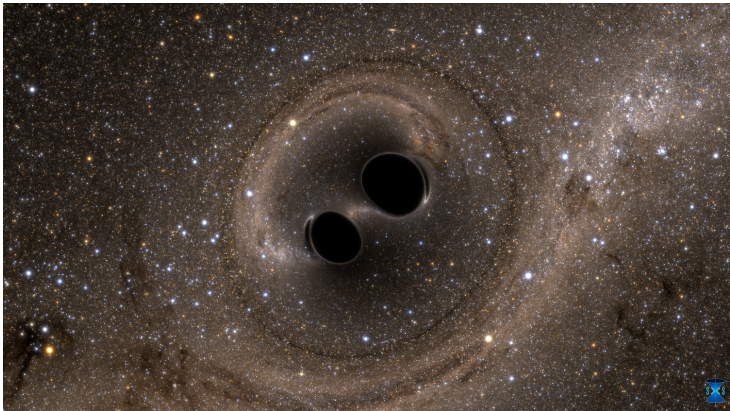
GW signal at 09:50:45 UTC on 14 September 2015



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

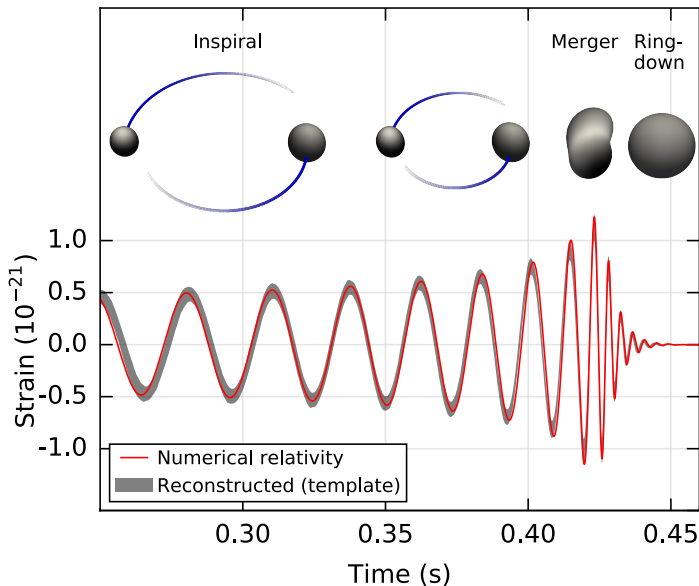
The sound of gravitational wave and simulated sky

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

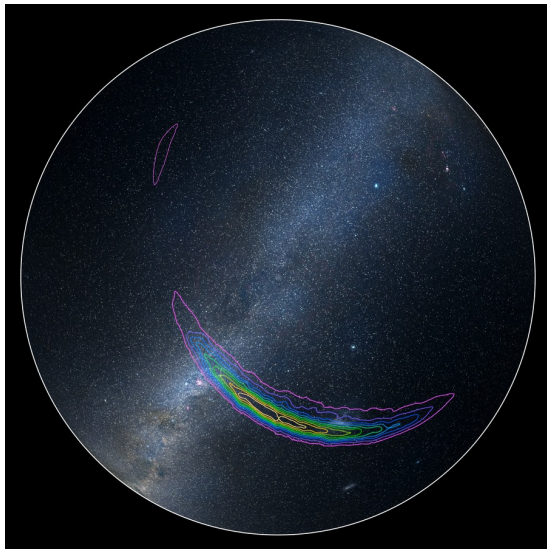


Two black holes with 29 and 36 solar masses merged about 1.3 billion years ago

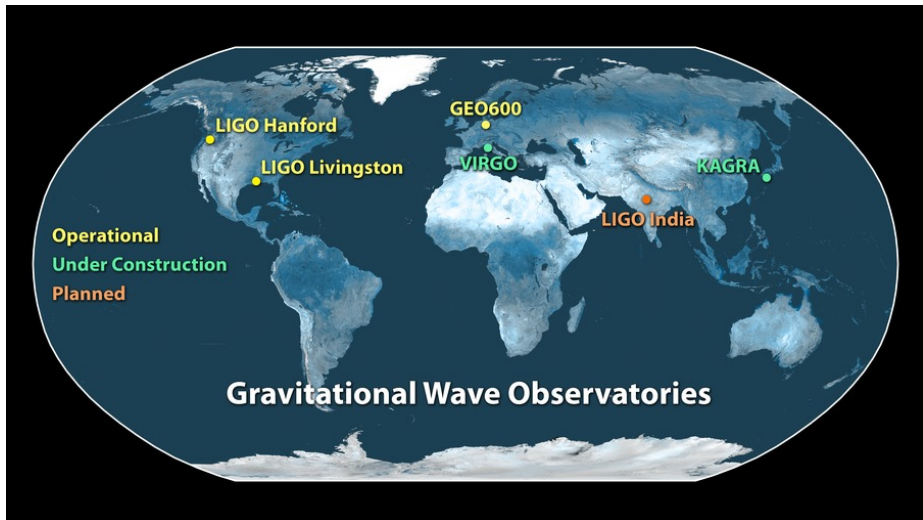
Reconstructed signal



GW source location at the southern hemisphere sky



World wide network of detectors



Seismic isolation



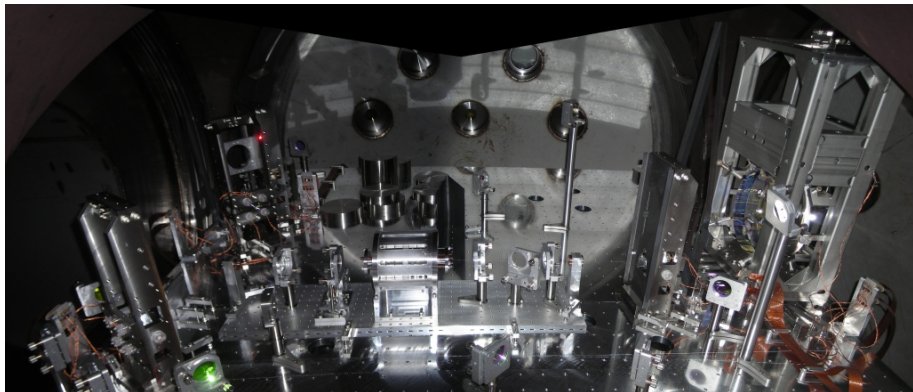
Part of large system



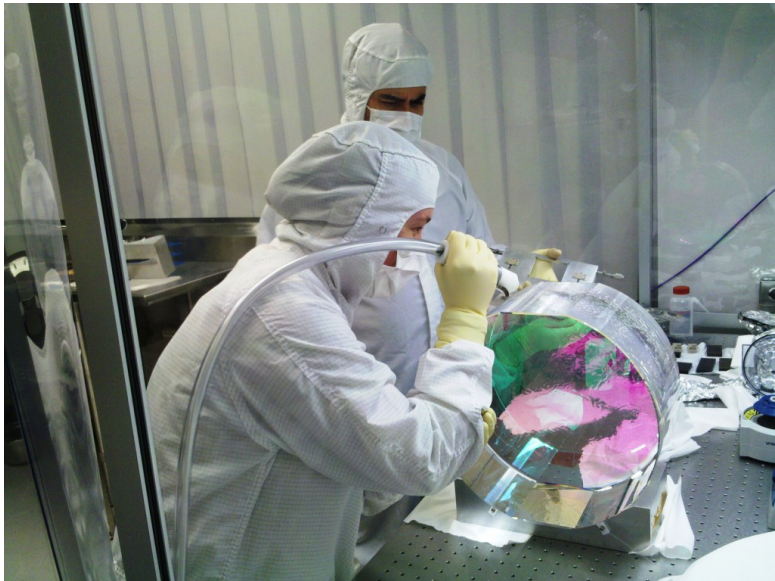
Work in chamber



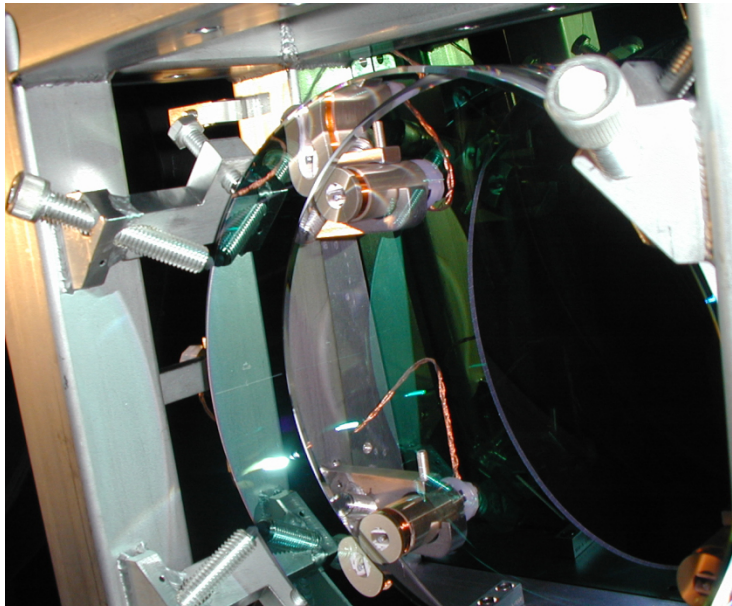
Inside vacuum chamber



Mirror



Inner test mass



We can catch GW but ...





**LIGO
Scientific
Collaboration**

www.ligo.org

Couple movies

- **LIGO Generations** <http://www.space.com/28409-ligo-generations-the-film-hd-video.html>
- **LIGO: A Passion for Understanding** <http://www.space.com/25455-ligo-documentary-film-complete-coverage.html>

You can help to detect a gravitational wave

www.einsteinathome.org

