Gravitational Wave Detection Videos

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LIGO: Laser Interferometer Gravitational-Wave Observatories

There is a third detector in Italy called Virgo

A Brief History of Gravitational Wave Detection

- Gravitational waves were predicted in 1916 by Einstein based on his General Theory of Relativity [which could be called his theory of gravity].
- About 1967 Rainer Weiss at MIT wrote a 23 page unpublished paper on how gravitational waves could be detected using a laser interferometer. It listed most of the potential problems involved and how they could be approached. Lasers had only been invented in 1960.
- On February 11, 2016 [100 years after Einstein's prediction], the LIGO and Virgo Scientific Collaboration announced they had made the first observation of gravitational waves. The observation itself was made on 14 September 2015, using the Advanced LIGO detectors. The gravitational waves originated from a pair of merging black holes. After the initial announcement the LIGO instruments detected two more confirmed, and one potential, gravitational wave events.
- In August 2017, but announced 15 October 2017, the two Advanced LIGO instruments, and the Advanced Virgo instrument, observed a fourth gravitational wave from merging black holes, and a fifth gravitational wave from a binary neutron star merger. Several other gravitational-wave detectors are planned or under construction.
- On 3 October 2017, the Nobel Prize in Physics was awarded to Rainer Weiss, Kip Thorne and Barry Barish for their role in the detection of gravitational waves.
- To date NSF has invested ~$1B in the LIGO effort. For comparison, the Hubble Space Telescope, a NASA project, cost ~$10B thru 2013. And the cost for the Large Hadron Collider at CERN to find the Higgs boson is ~$ 13B.
  - This information is mostly from Wikipedia

Gravitational Wave Detection Videos:

Rainer Weiss presentation (~ 1 hr)**:**

https://www.youtube.com/watch?v=DNpFsDgq0Bw

Virgo animation (< 4 min.):

https://www.youtube.com/watch?v=h_FbHipV3No

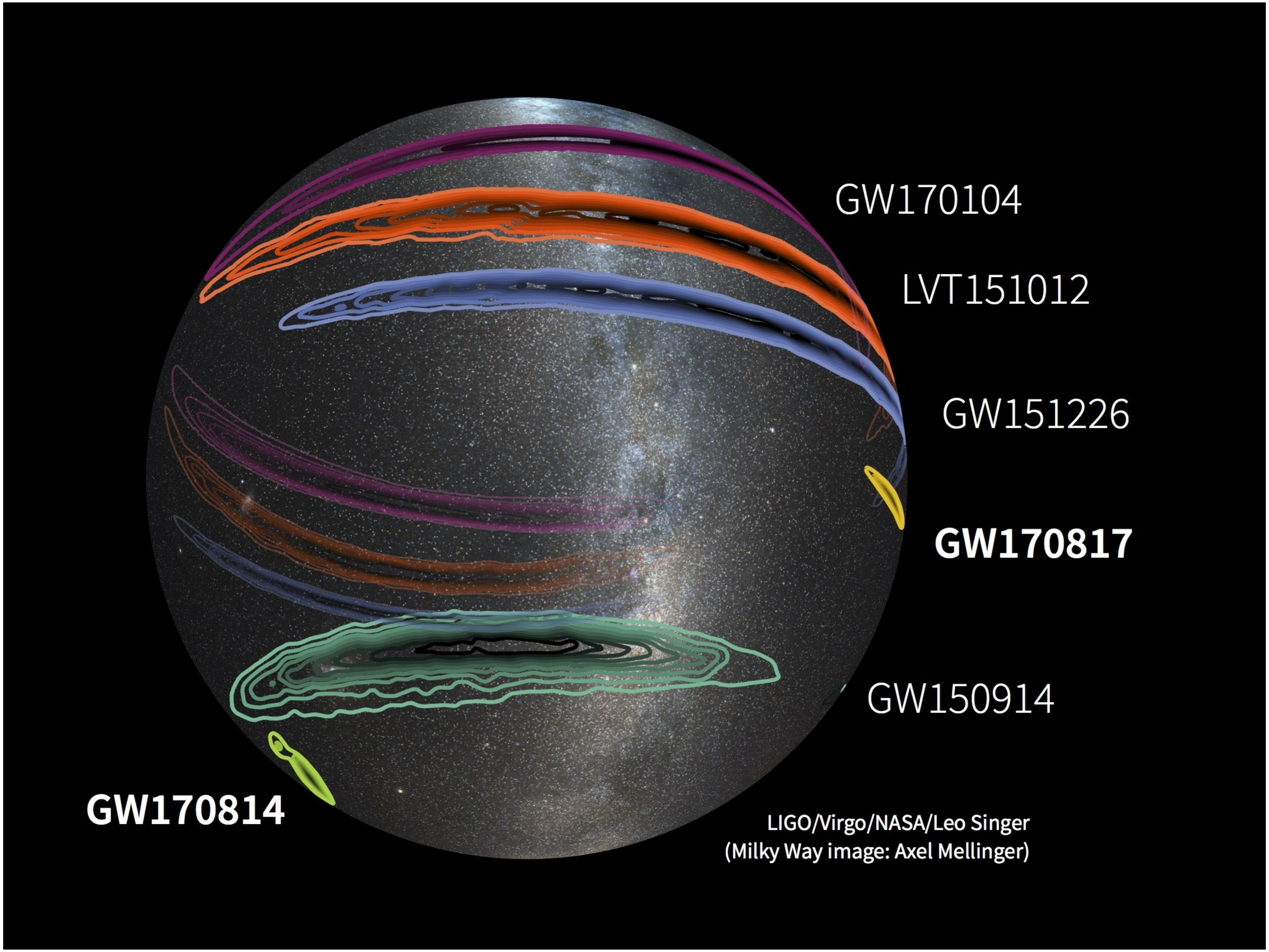
The Absurdity of Detecting Gravitational Waves (~ 9 min.):

https://www.youtube.com/watch?v=iphcyNWFD10

How Scientists Reacted to Gravitational Wave Detection – it was not and an eureka moment (~ 9 min.):

https://www.youtube.com/watch?v=ViMnGgn87dg

Directivity of the gravitational waves sensed so far



From: https://www.ligo.caltech.edu/page/press-release-gw170817

VIRGO did not directly detect GW170817 but it significantly helped localize it

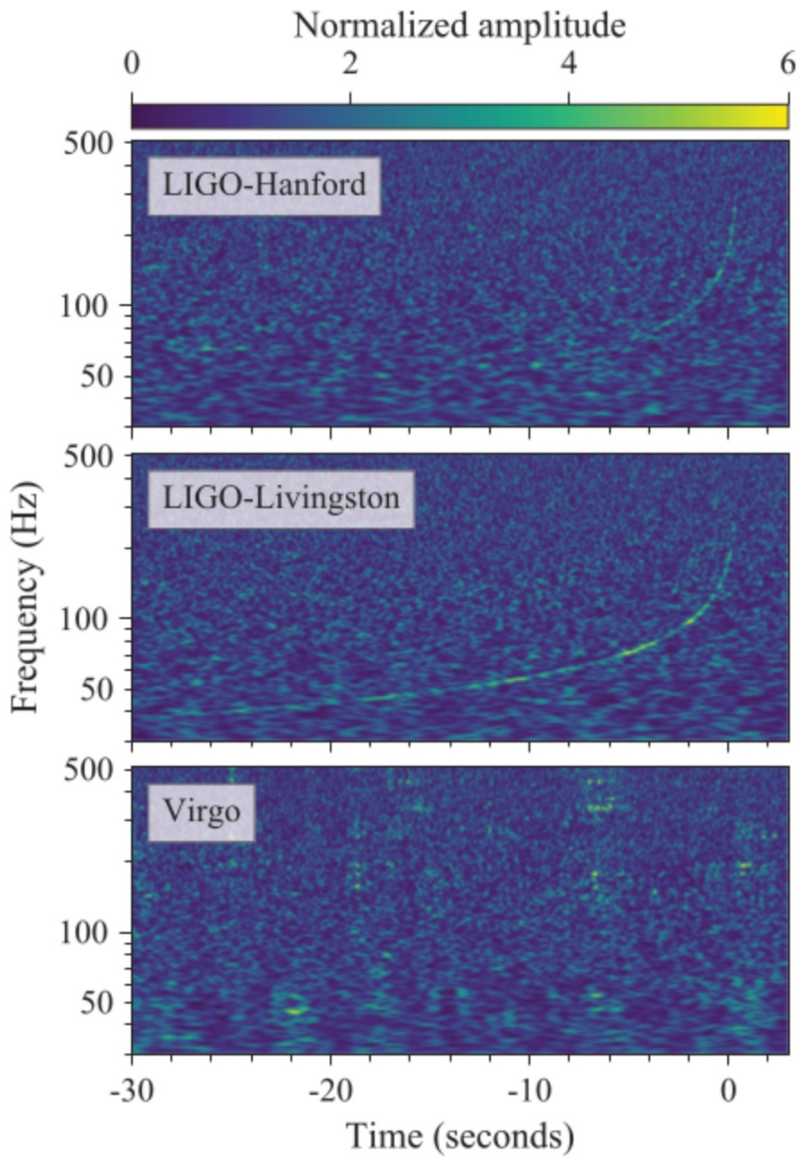


FIG. 1. Time-frequency representations [65] of data containing the gravitational-wave event GW170817, observed by the LIGO-Hanford (top), LIGO-Livingston (middle), and Virgo (bottom) detectors. Times are shown relative to August 17, 2017 12:41:04 UTC. The amplitude scale in each detector is normalized to that detector's noise amplitude spectral density. In the LIGO data, independently observable noise sources and a glitch that occurred in the LIGO-Livingston detector have been subtracted, as described in the text. This noise mitigation is the same as that used for the results presented in Sec. IV.

From: GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

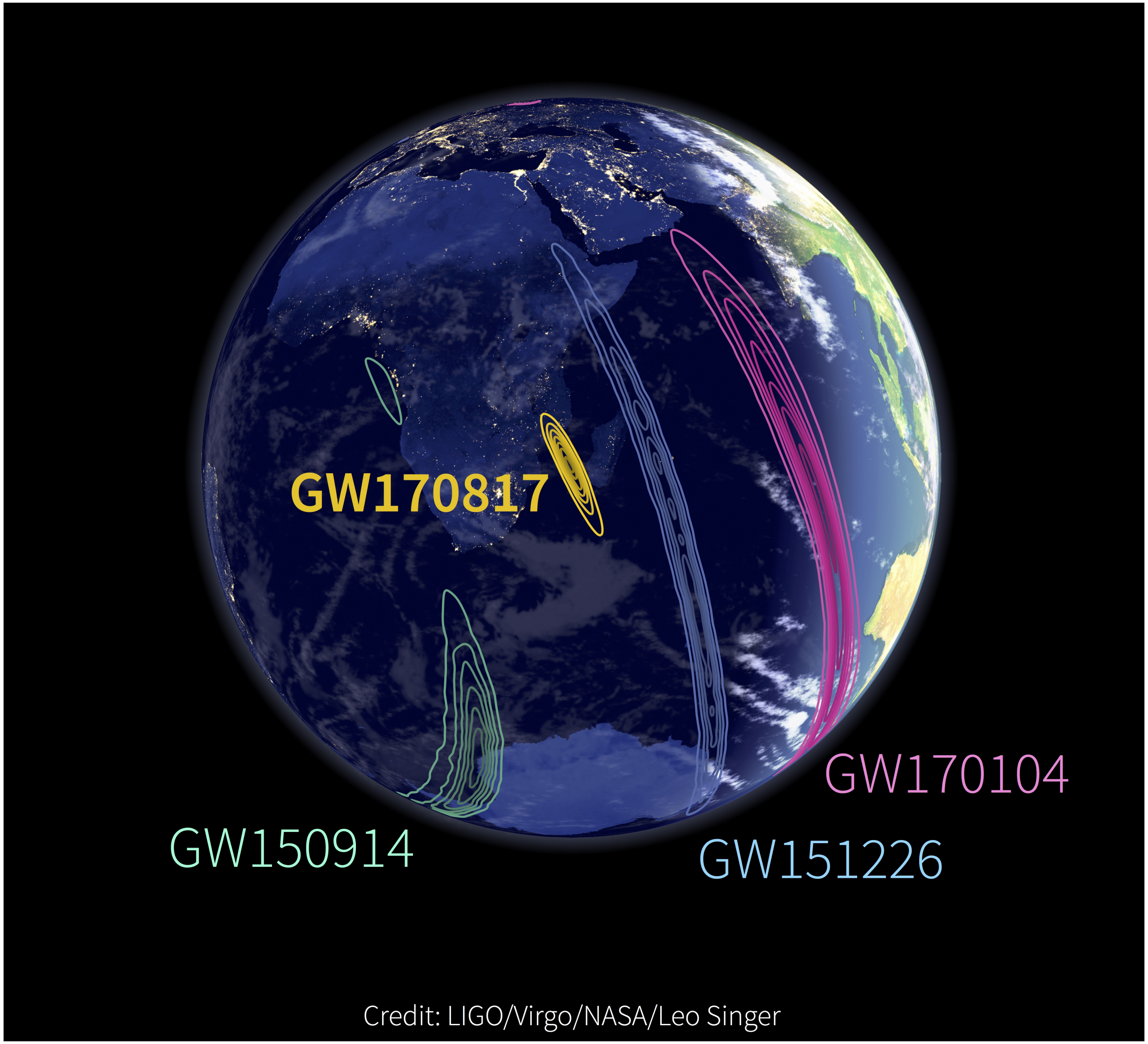
B. P. Abbott et al.

(Published 16 October 2017)

Listen to audio:
https://losc.ligo.org/audio/
https://www.youtube.com/watch?v=aWX-BY-A9CY
https://www.youtube.com/watch?v=wCWgl7OzvUk

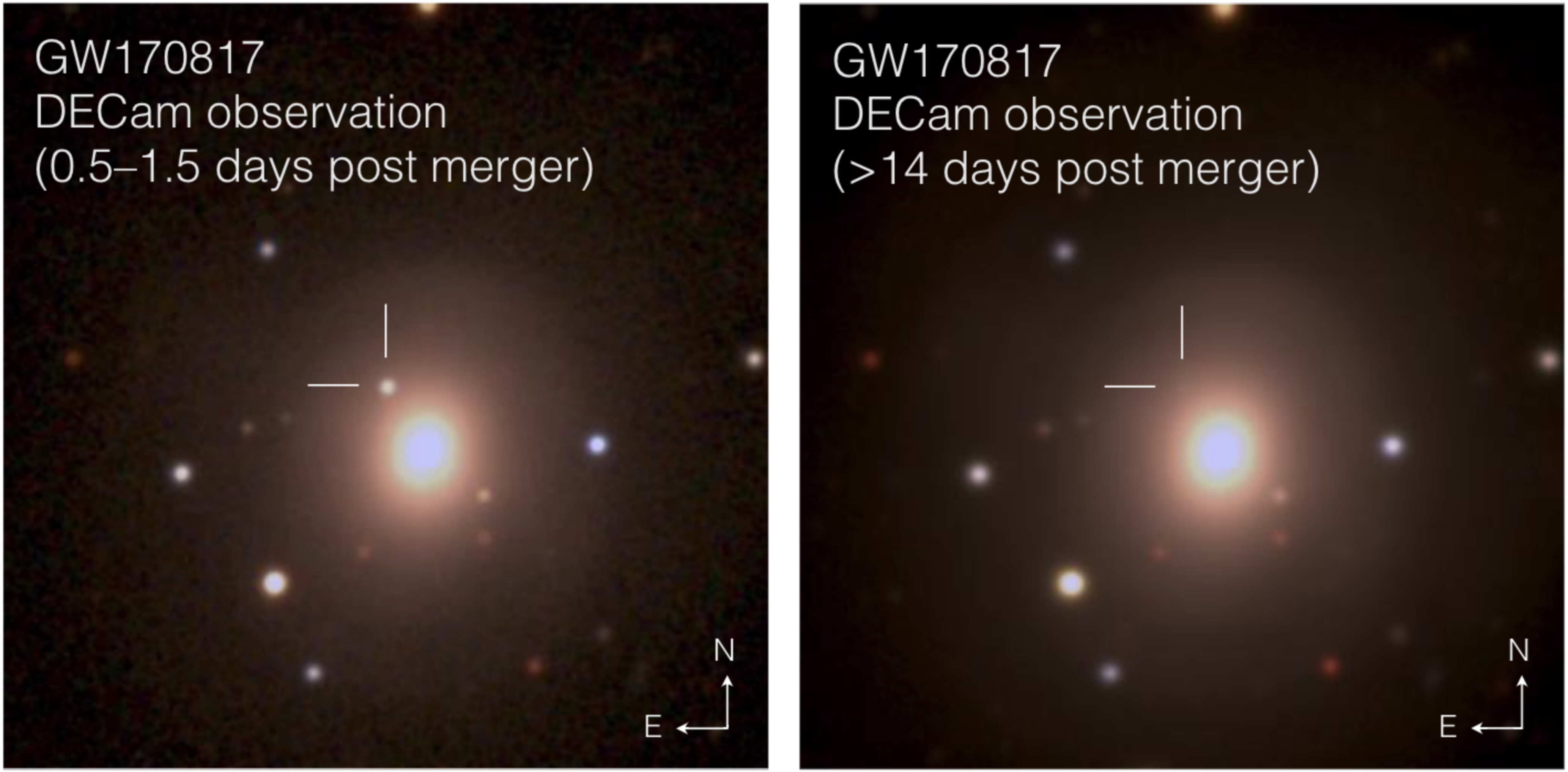
LIGO is currently paused but will start running again in Fall 2018 for the O3 run (joint with Virgo).

Directivity of some of the gravitational waves sensed so far



From: http://ligo.org/detections/GW170817.php
Also see the video at that site

Disappearing Neutron Stars



Neutron star pair appears and then disappears near elliptical
Galaxy NGC 4993: http://ligo.org/detections/GW170817.php
Such an event is referred to as a kilonovas.

LIGO Directivity

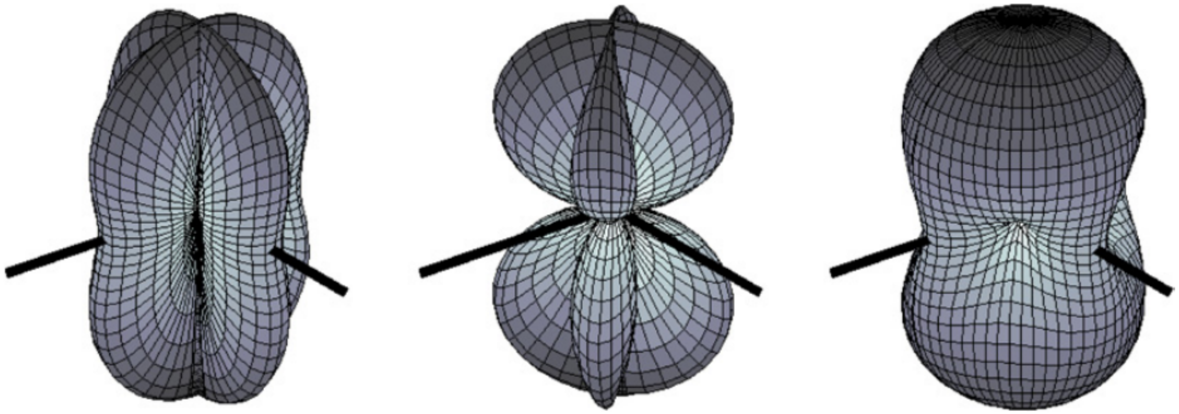
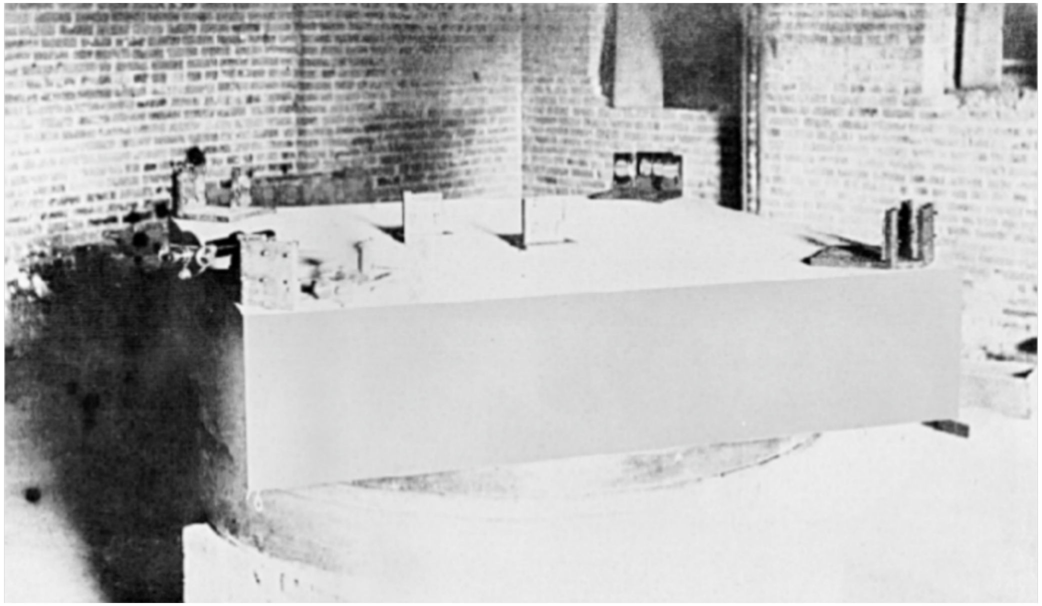


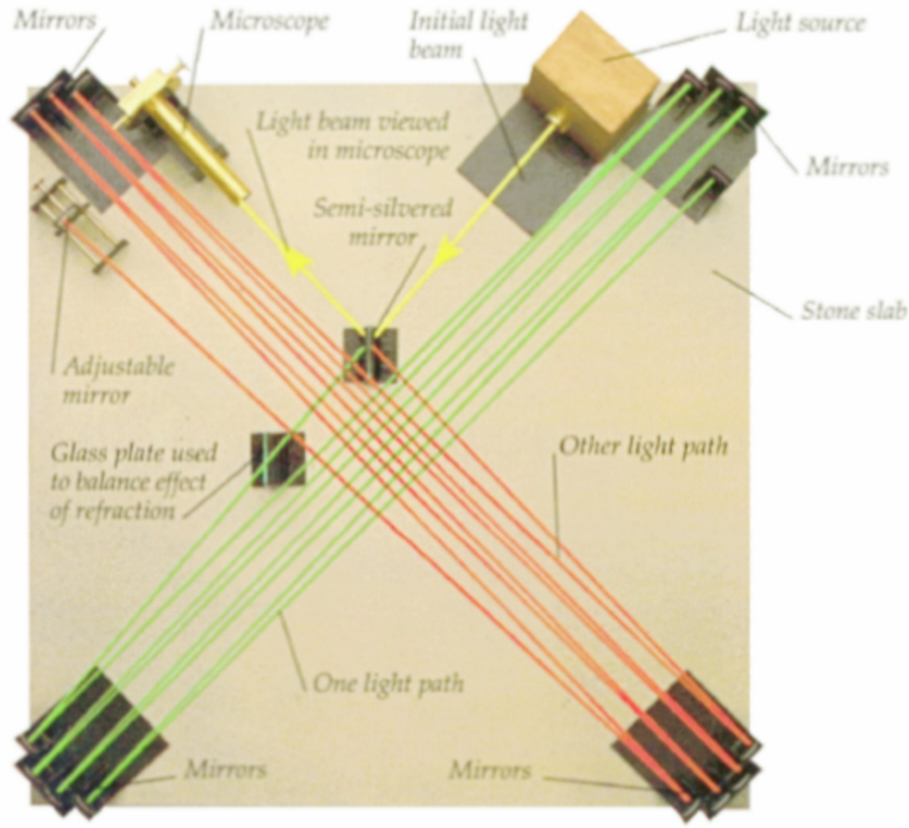
Figure 5. Antenna response pattern for a LIGO GW detector, in the long-wavelength approximation. The interferometer beamsplitter is located at the center of each pattern, and the thick black lines indicate the orientation of the interferometer arms. The distance from a point of the plot surface to the center of the pattern is a measure of the GW sensitivity in this direction. The pattern on the left is for + polarization, the middle pattern is for × polarization and the right-most one is for unpolarized waves.

Ref.: B P Abbott et al 2009 Rep. Prog. Phys. 72 076901

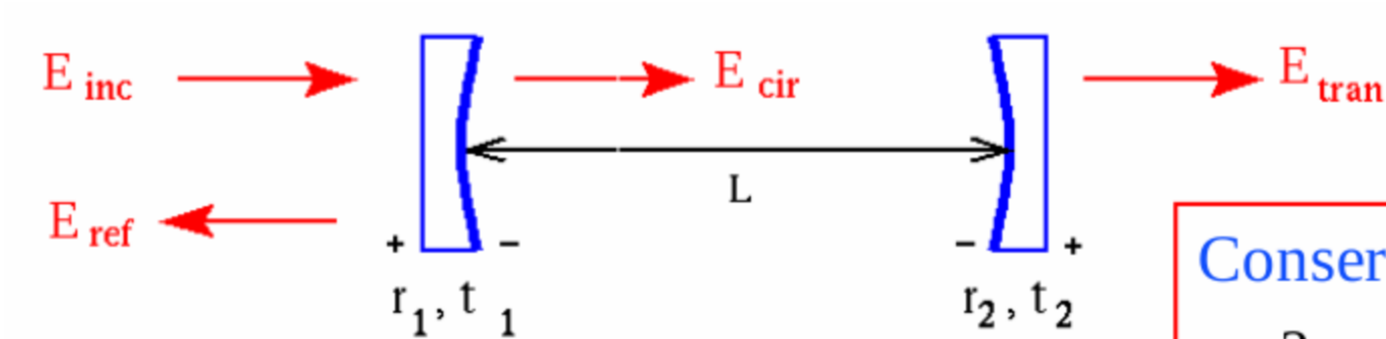
Michelson-Morley Interferometer

Used (circa 1885) to show that the speed of light is independent of direction – hence no aether





Fabry-Perot Optical Resonator Cavities



$$E_{cir} = t_1 E_{inc} + r_1 r_2 e^{-2ikL} E_{cir} = \frac{t_1}{1 - r_1 r_2 e^{-2ikL}} E_{inc}$$

$$E_{ref} = r_1 E_{inc} - t_1 r_2 e^{-2ikL} E_{cir} = \frac{r_1 - r_2 (1 - L) e^{-2ikL}}{1 - r_1 r_2 e^{-2ikL}} E_{inc}$$

$$E_{tran} = t_2\ e^{-ikL} E_{cir} = \frac{t_1 t_2 e^{-ikL}}{1 - r_1 r_2 e^{-2ikL}} E_{inc}$$

Conservation of energy:

$$r_i^2 + t_i^2 + L_i = 1$$

$$R_i + T_i + L_i = 1$$

When $2kL = n(2\pi)$, (ie, $L = n\lambda/2$),

E_{cir} , E_{tran} maximized $\Rightarrow$ resonance!