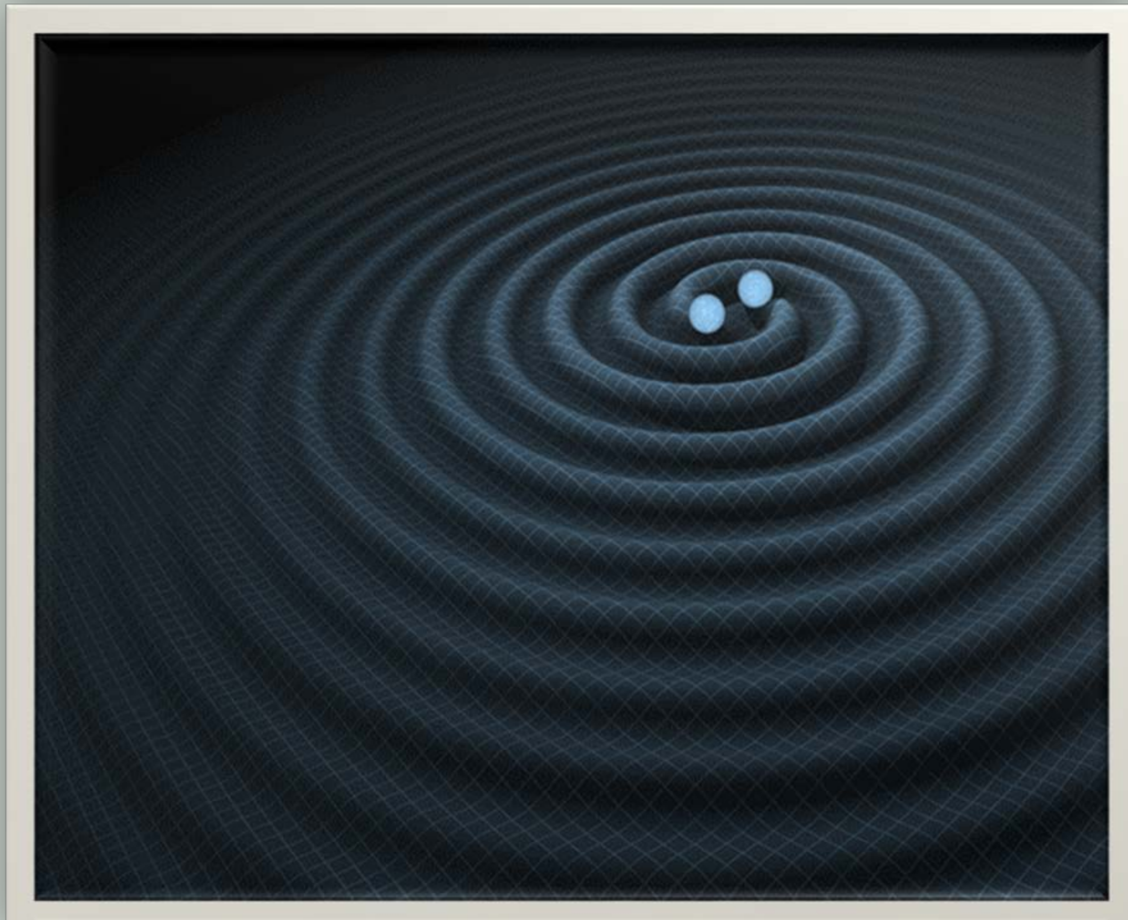
Gravitational Waves



Ananthavishnu S U

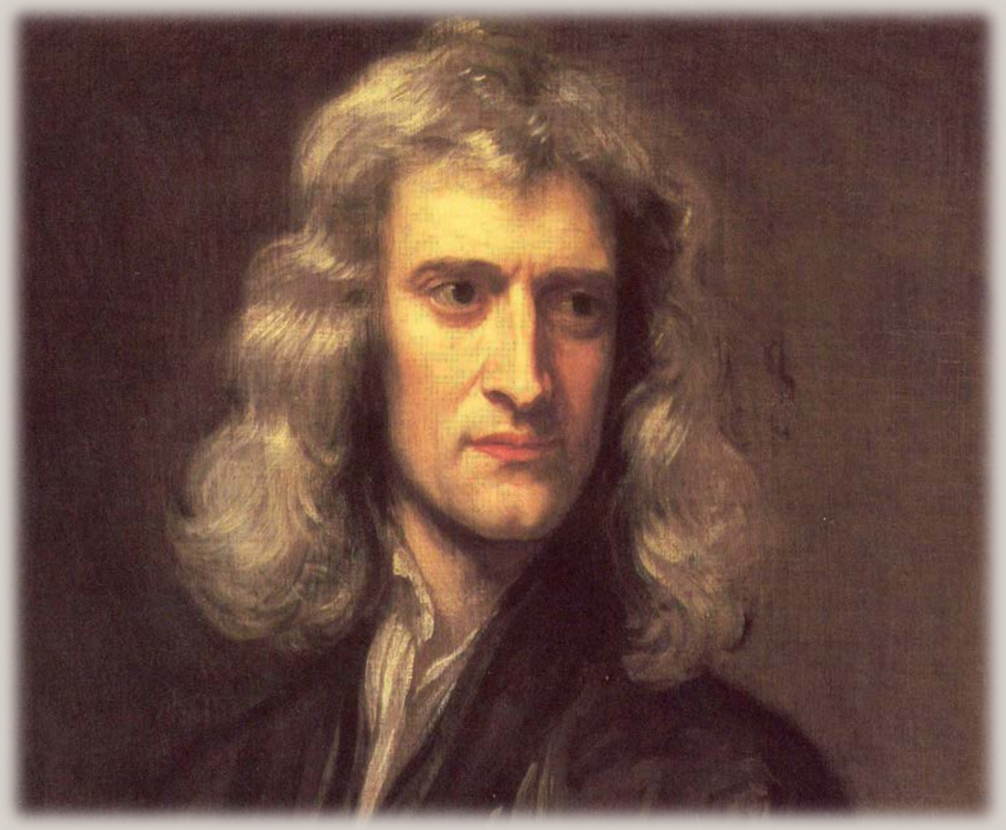
October 7, 2022

Department of Physics and Astronomy

University of South Carolina

Agenda

01 Gravity



First proper study by Sir Isaac Newton

He considered gravity as a Universal Force.

Newton's law of universal gravitation :

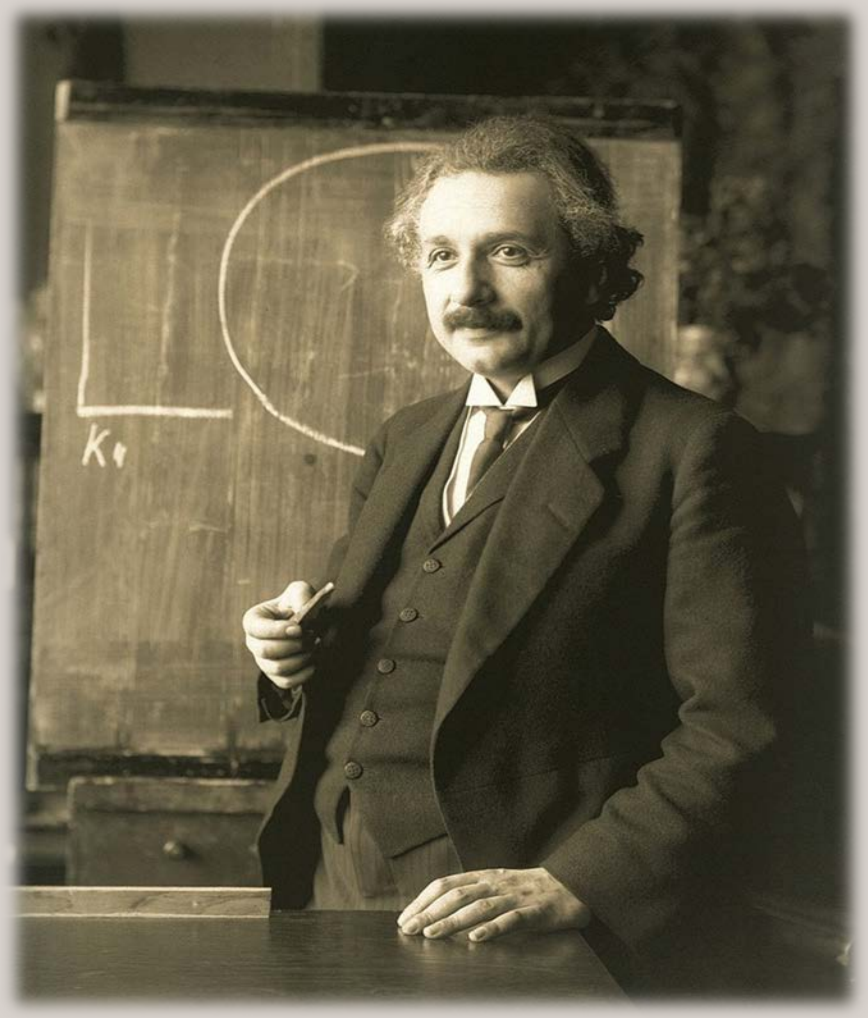
“Every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers”

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

“If I have seen further than others, it is by standing upon the shoulders of giants” – Sir Issac Newton

01

Gravity



Best study by Albert Einstein

He considered gravity as a space-time curvature.

Einstein proposed that spacetime is curved by matter or energy.

Free-falling objects are moving along locally straight paths in curved spacetime called geodesics.

This idea is governed by Einstein’s Field equations:

$$G_{\mu v} + \Lambda g_{\mu v} = \frac{8\pi G}{c^4} T_{\mu v}$$

Where,

$G_{\mu v}$ - Einstein tensor

Λ - Cosmological constant

$g_{\mu v}$ - Metric tensor

$T_{\mu v}$ - Stress–energy tensor

02 Spacetime

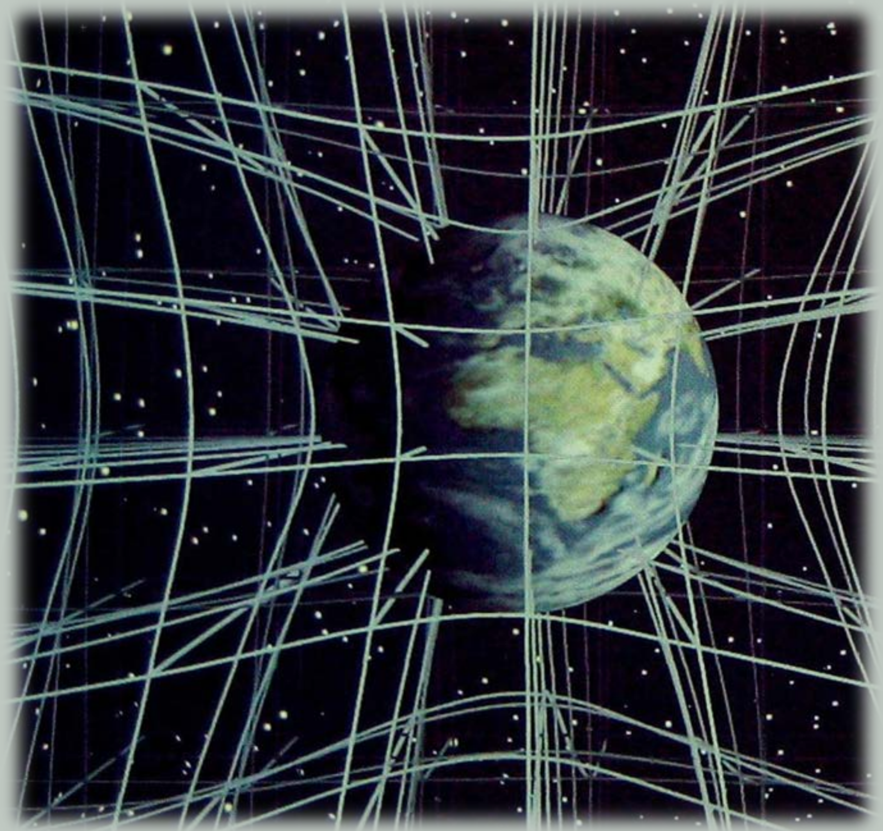


Fig 2: Spacetime
© ESA–C.Carreau

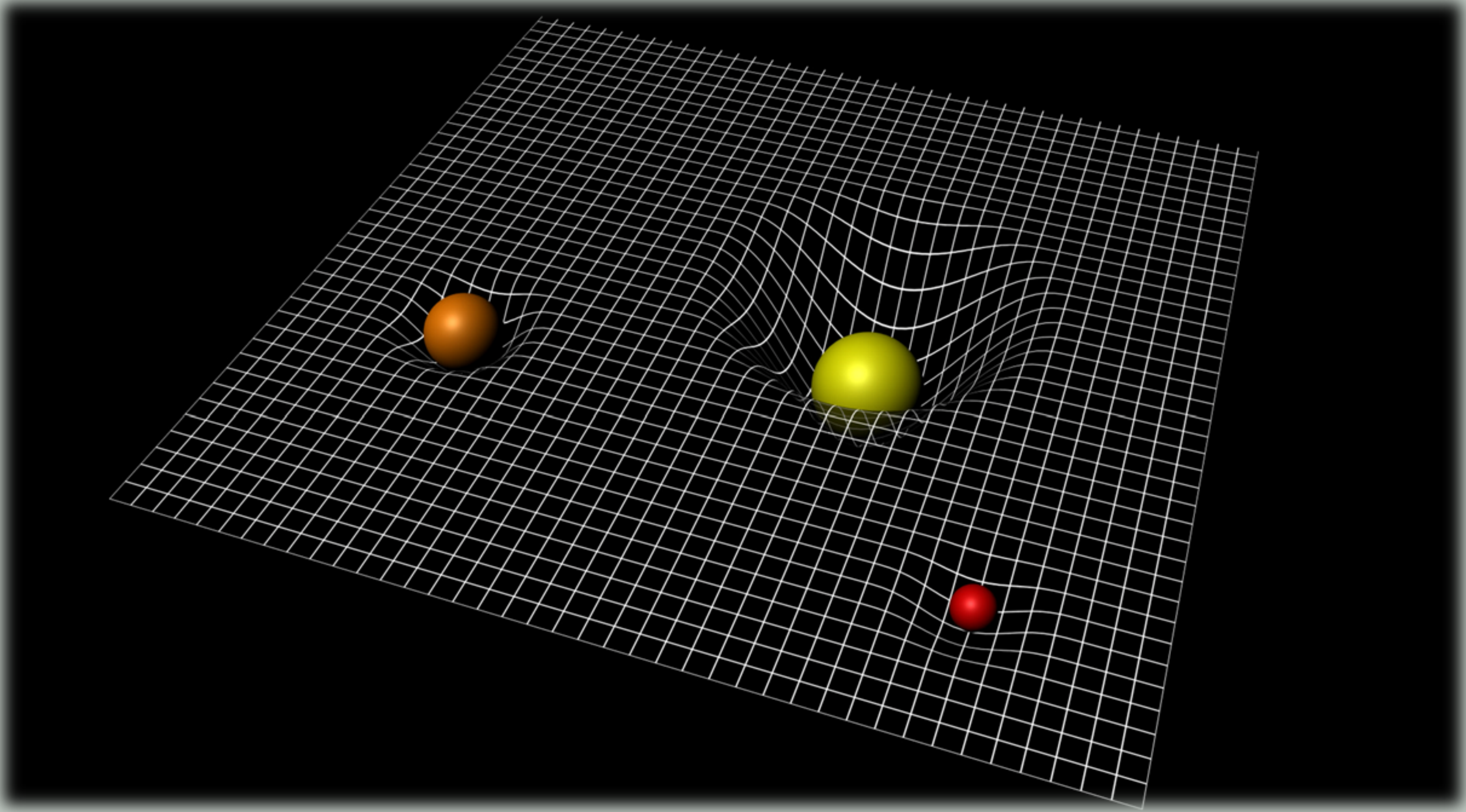


Fig 1: Space time in a plane
©ESA–C.Carreau

A mathematical model that combines the three dimensions of space and one dimension of time into a single four-dimensional manifold

03 Gravitational Wave

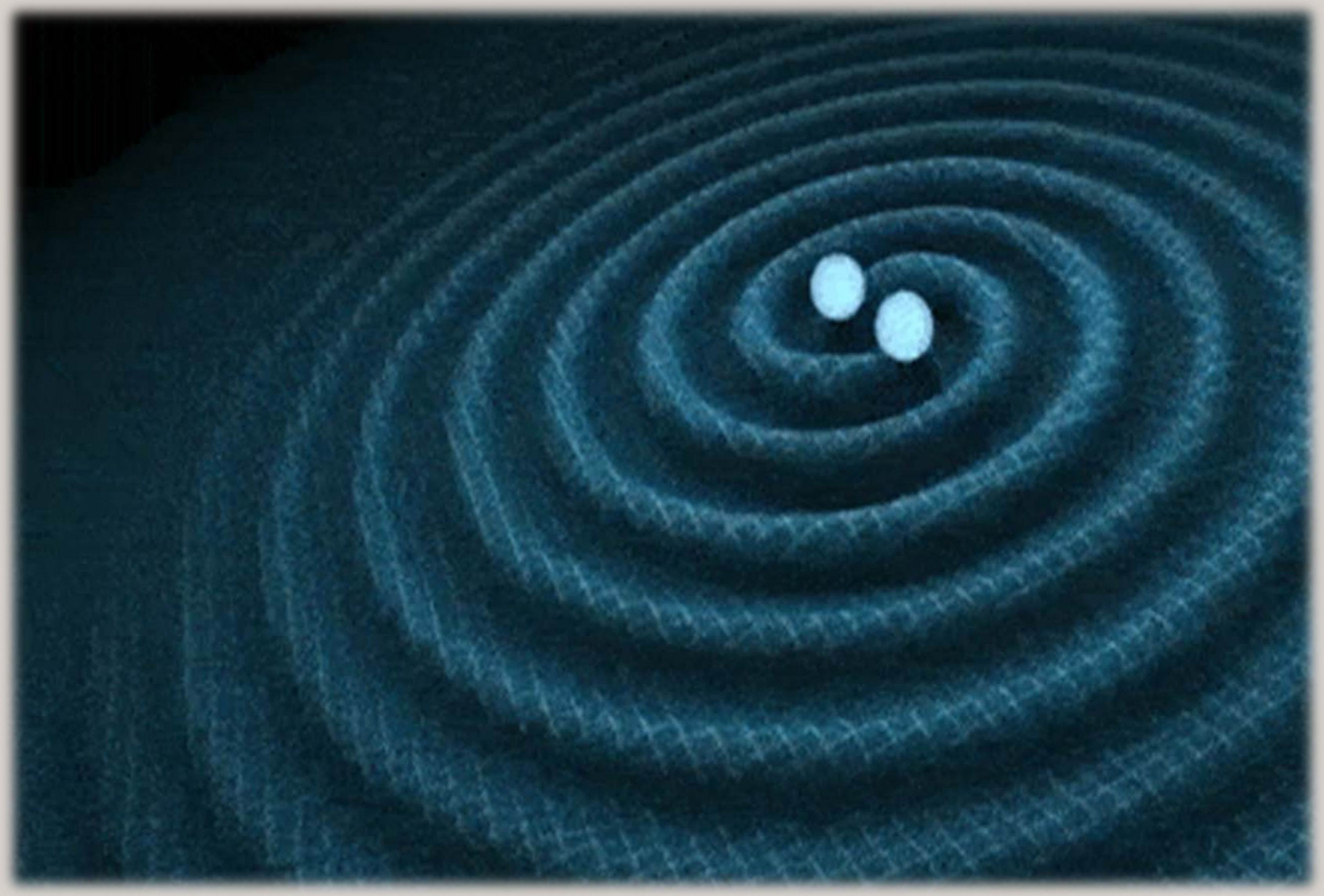


Fig 3: Space time in a plane
©ESA–C.Carreau

03 Gravitational Wave

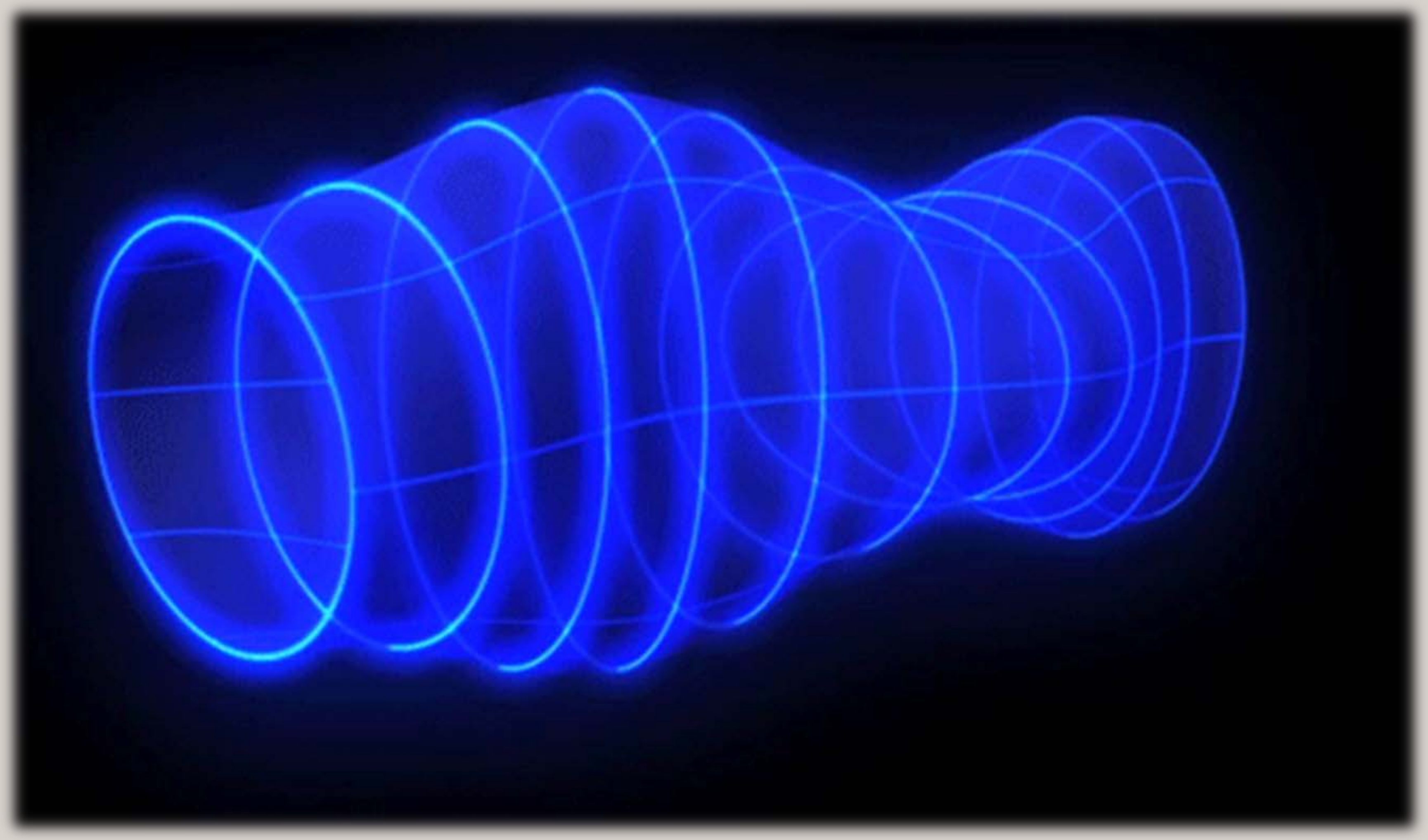


Fig 4: Spacetime in dimension ©ESA–C.Carreau

04 Characteristics of GW

Cosmic gravitational waves are produced by coherent, bulk motions of huge amounts of mass-energy—either material mass, or the energy of vibrating, nonlinear spacetime curvature.

The wavelengths of cosmic gravitational waves are comparable to or larger than their coherent, bulk-moving sources, so we cannot make pictures from them.

Gravitational waves travel nearly unscathed through all forms and amounts of intervening matter

Gravitational waves will show us details of the bulk motion of dense concentrations of energy

Gravitational waves propagates with the speed of light

05 Detection Method

Ground-Based Laser Interferometers:

Laser Interferometer Gravitational wave Observatory. (LIGO)

VIRGO

Both of them are based on Michelson interferometer.

LIGO is in United States and is taken care by Caltech.

VIRGO is in Italy and is taken care by European Gravitational Observatory (EGO)

Bandwidth: $1 - 10^4 Hz$

Measure a motion 10,000 times smaller than an atomic nucleus

05 Detection Method

Laser Interferometer Gravitational wave Observatory. (LIGO)

Based on Michelson interferometer.

LIGO is in United States and is taken care by Caltech.

2 LIGOs : LIGO Hanford and LIGO Livingston

Each arm length : 4Km

Fig 5: LIGO Hanford
©LIGO

Fig 6: LIGO Livingston
©LIGO

06 Working of LIGO

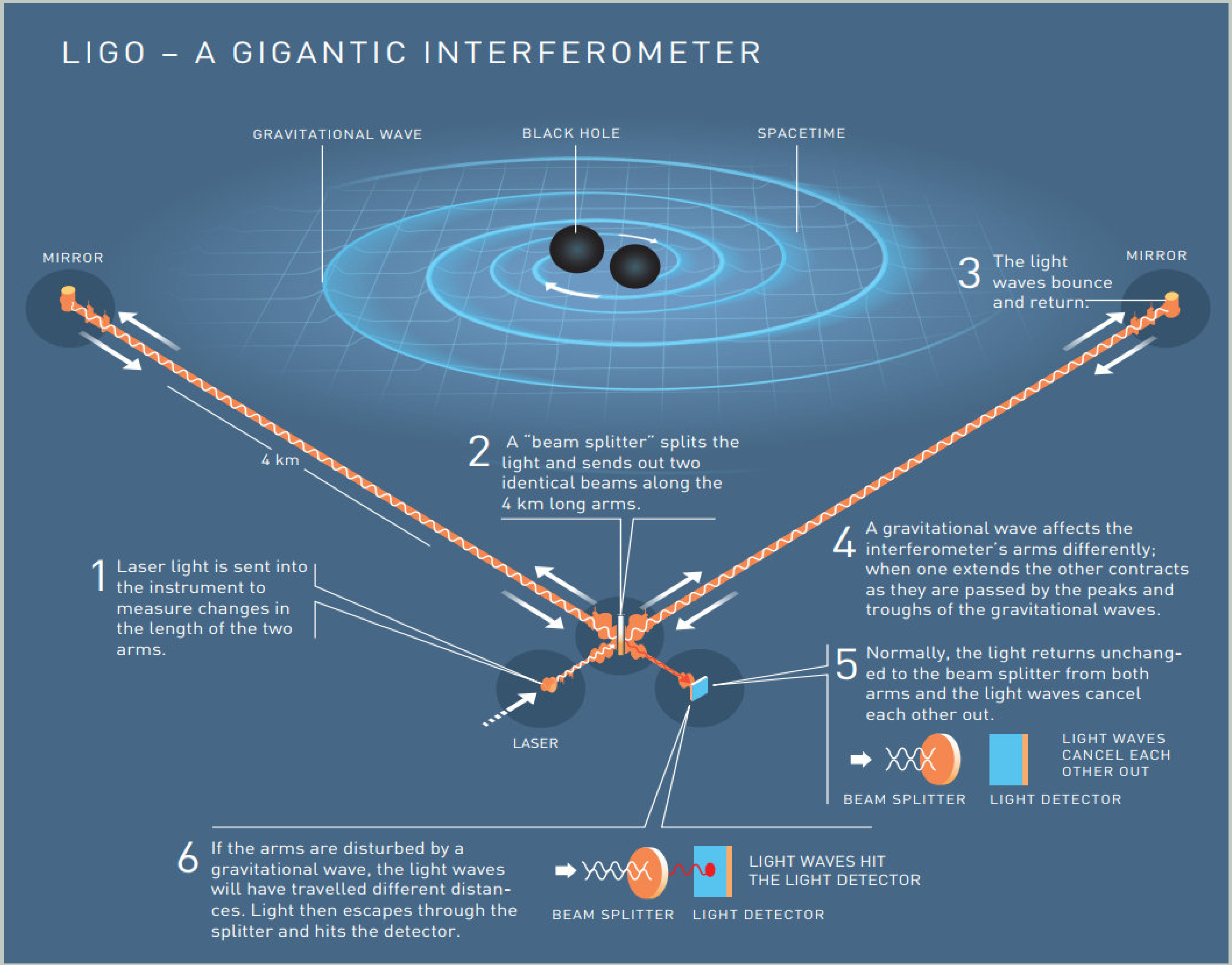


Fig 7
© The Nobel Prize

06 Working of LIGO

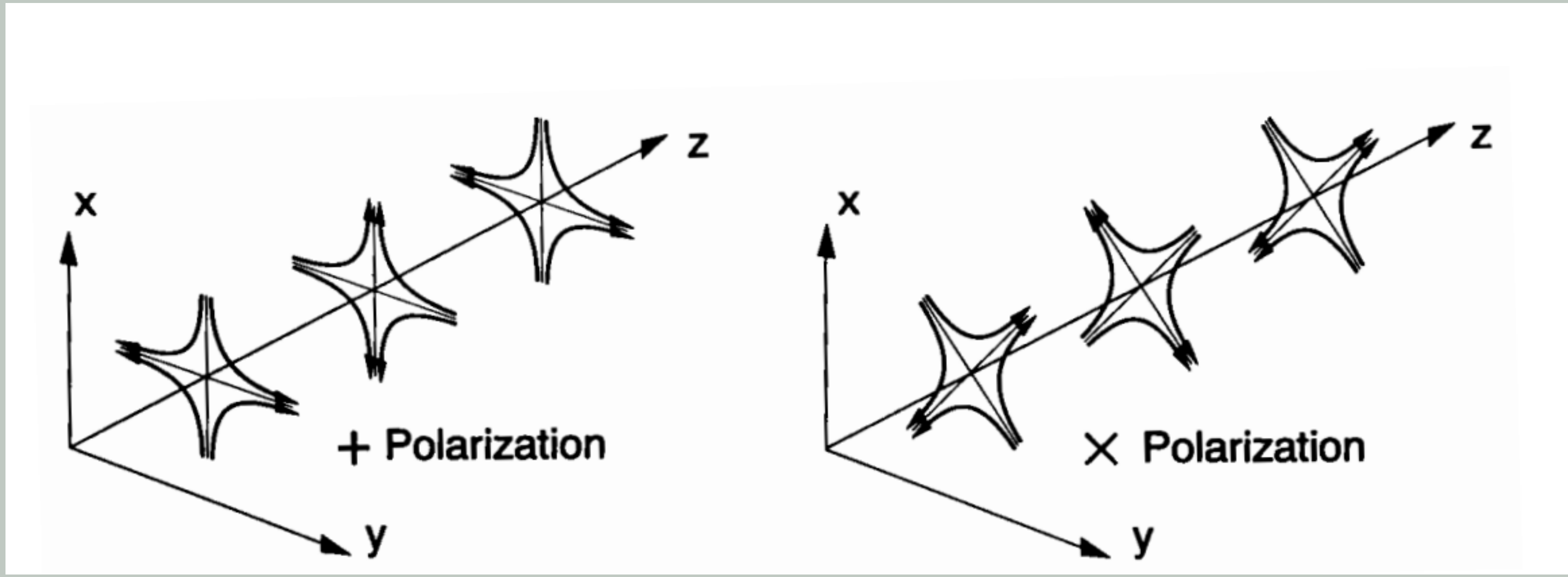


Fig 8: The lines of force associated with the two polarizations of a gravitational wave.

06 Working of LIGO

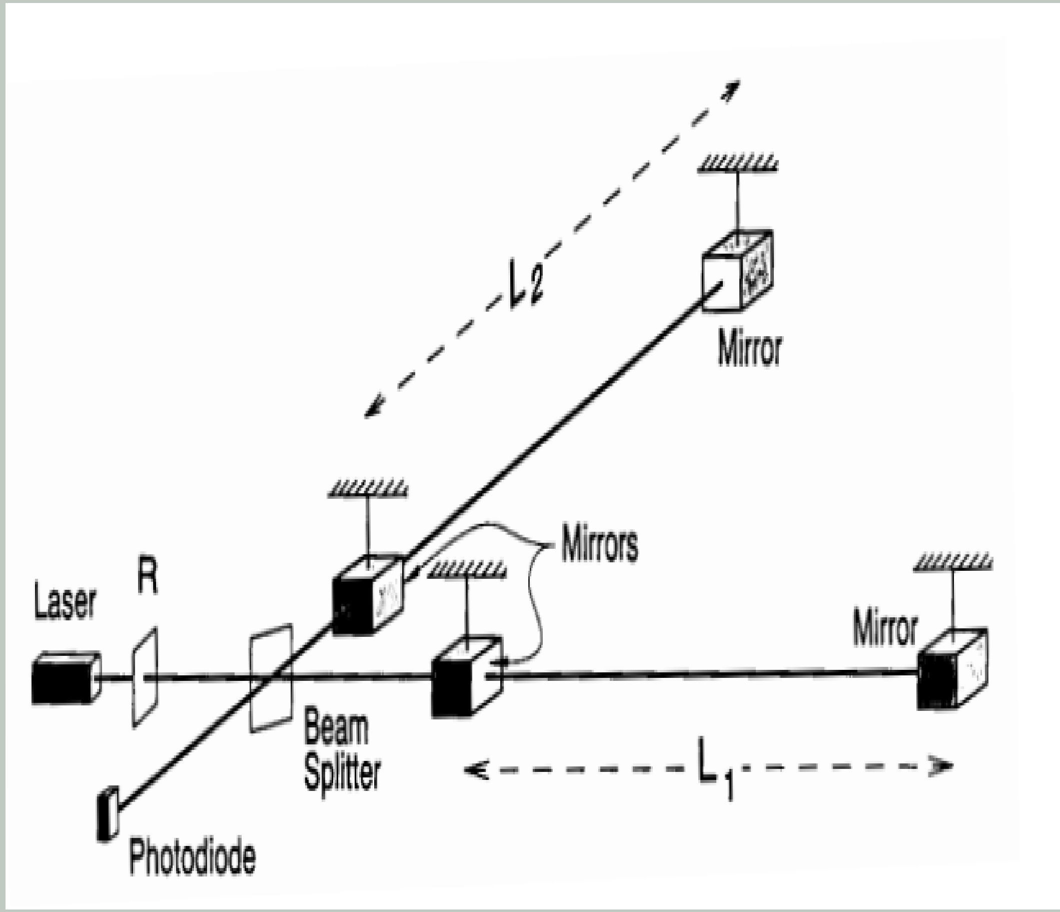


Fig 9: Schematic diagram of a laser interferometer gravitational wave detector
©LIGO

$$\frac{\Delta L}{L} = F_+ h(t)_+ + F_X h(t)_X \equiv h(t)$$

Where,

$\Delta L = L1 - L2$ (Change in arm length)
$h(t)$ is gravitational wave strain

Here two fs are the coefficients.

© Gravitational Waves, Kip S. Thorne

07 Detection

First observation of gravitational waves:

On 14 September 2015

From the inward spiral and merger of a pair of black holes of around 36 and 29 solar masses and the subsequent "ringdown" of the single resulting black hole of 62 solar mass.

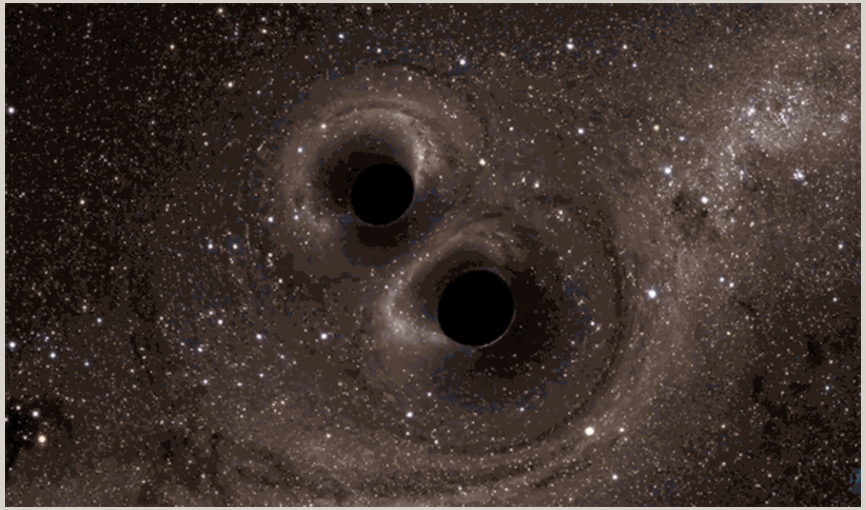
Energy equivalent to 3 solar masses was emitted over a few tenths of a second.

The signal was named GW150914

From 1.3 billion light-years away

07 Detection

GW150914



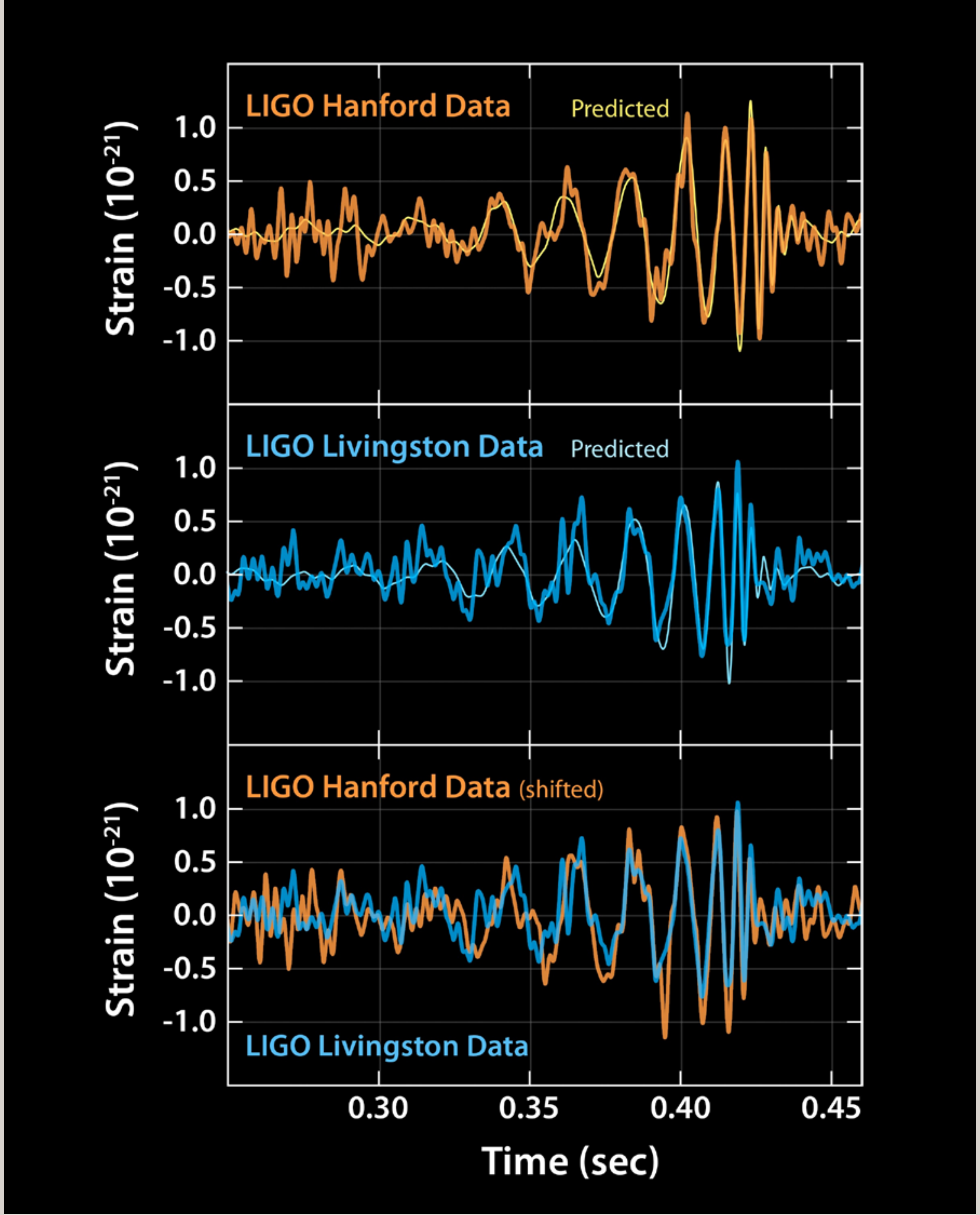


Fig 10: LIGO Detection
©LIGO

07 Detection

GW170814

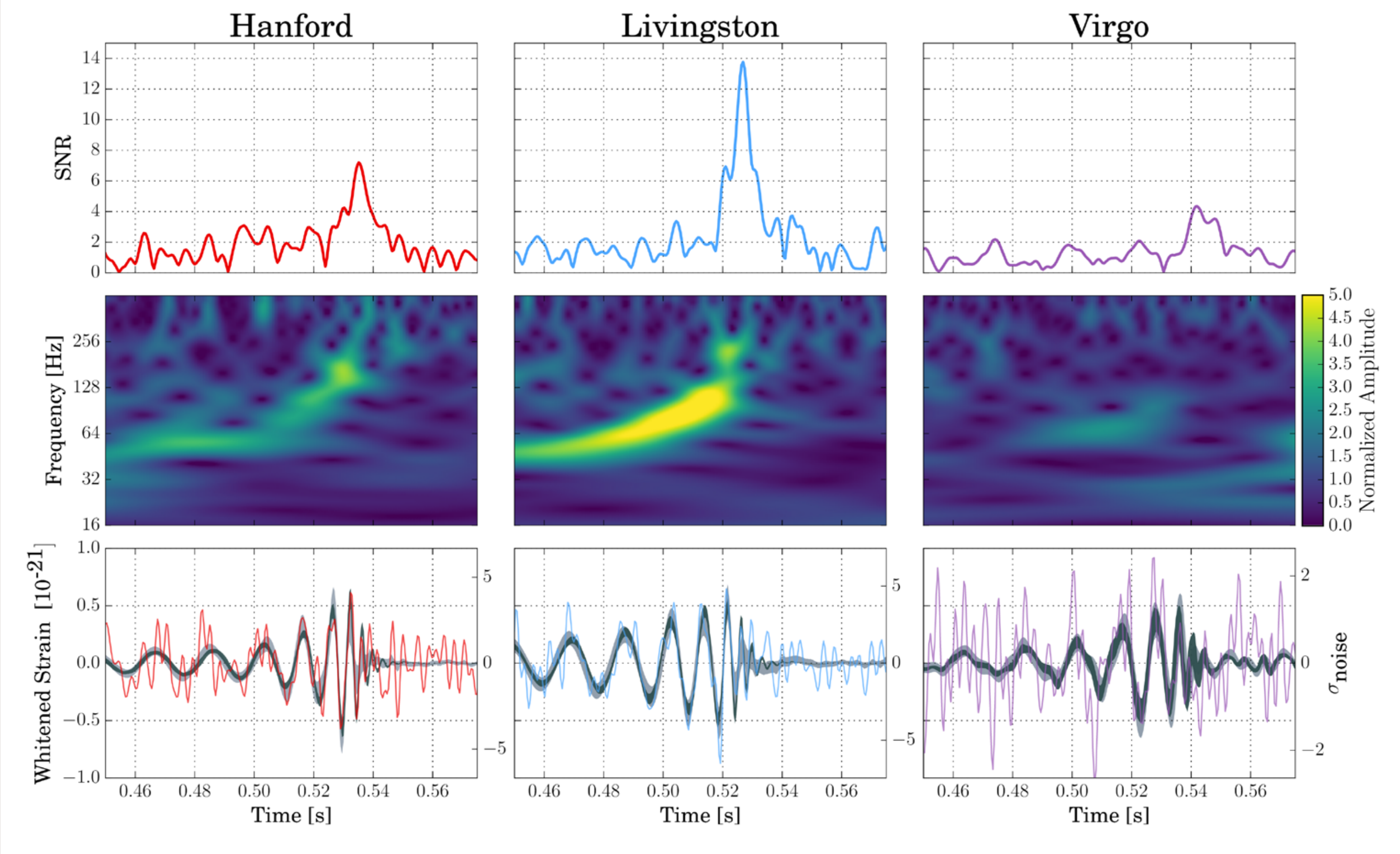


Fig 11: LIGO Detection ©LIGO

Summary

Gravity is a space-time curvature.

Energy or matter can curve spacetime

Gravitational waves propagates with the speed of light

Gravitational waves will show us details of the bulk motion of dense concentrations of energy

Detection by Interferometer

2017 Nobel Prize: Rainer Weiss, Barry C. Barish and Kip S. Thorne