# Gravitational Waves

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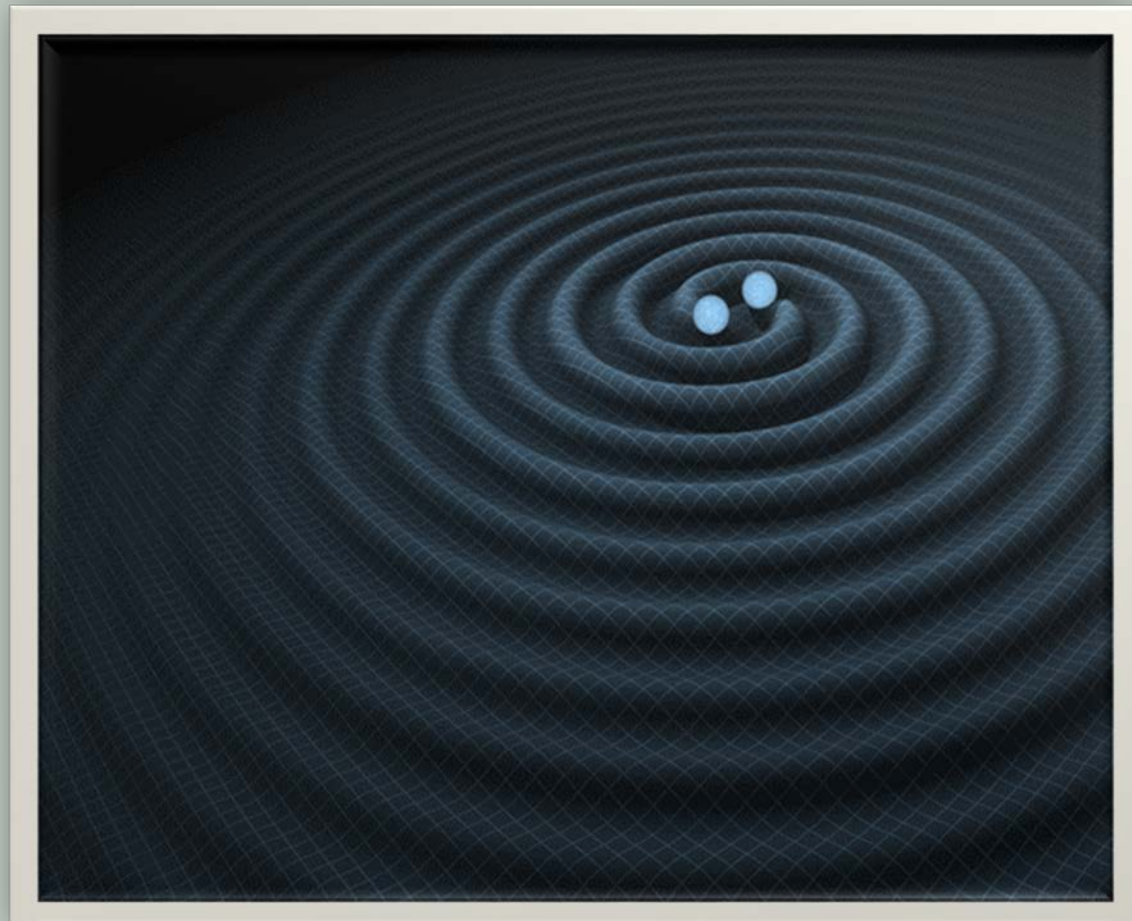


# Agenda

01 Gravity

02 Spacetime

03 Gravitational Wave

04 Characteristics of GW

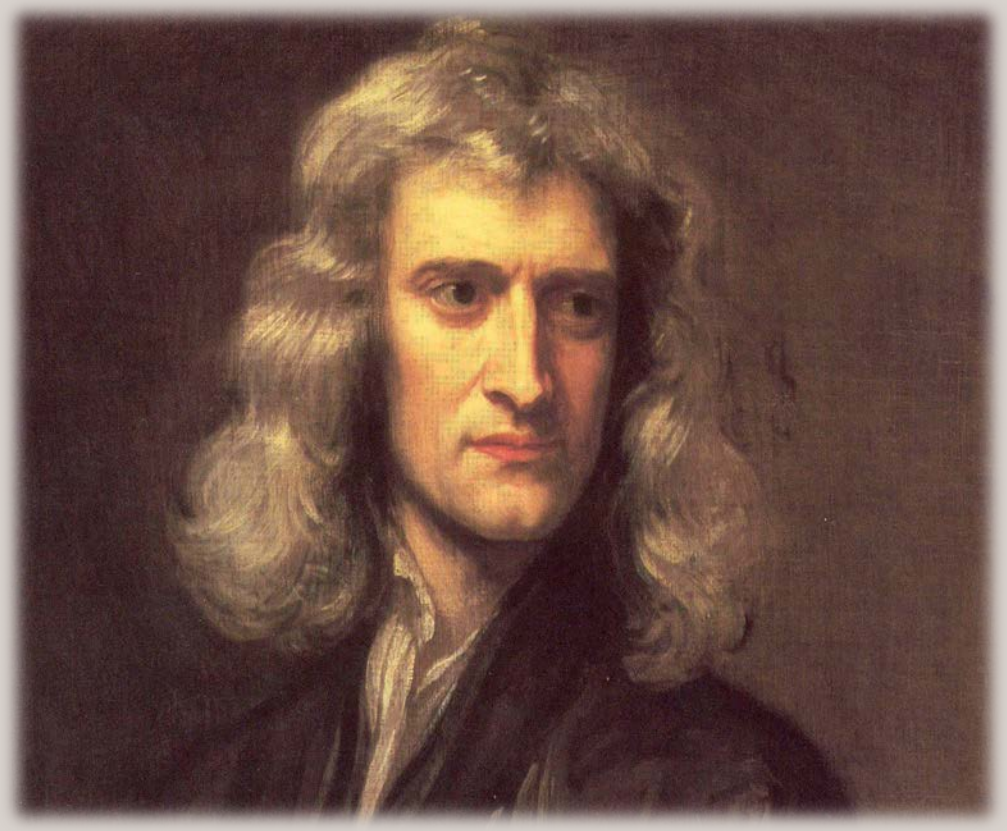
05 Detection Method

06 Working of LIGO

07 Detection

08 Summary

# 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 centres”

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

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

# 01 Gravity

- Albert Einstein proposed that spacetime is curved by matter or energy.
- This idea is governed by Einstein's Field equations:

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

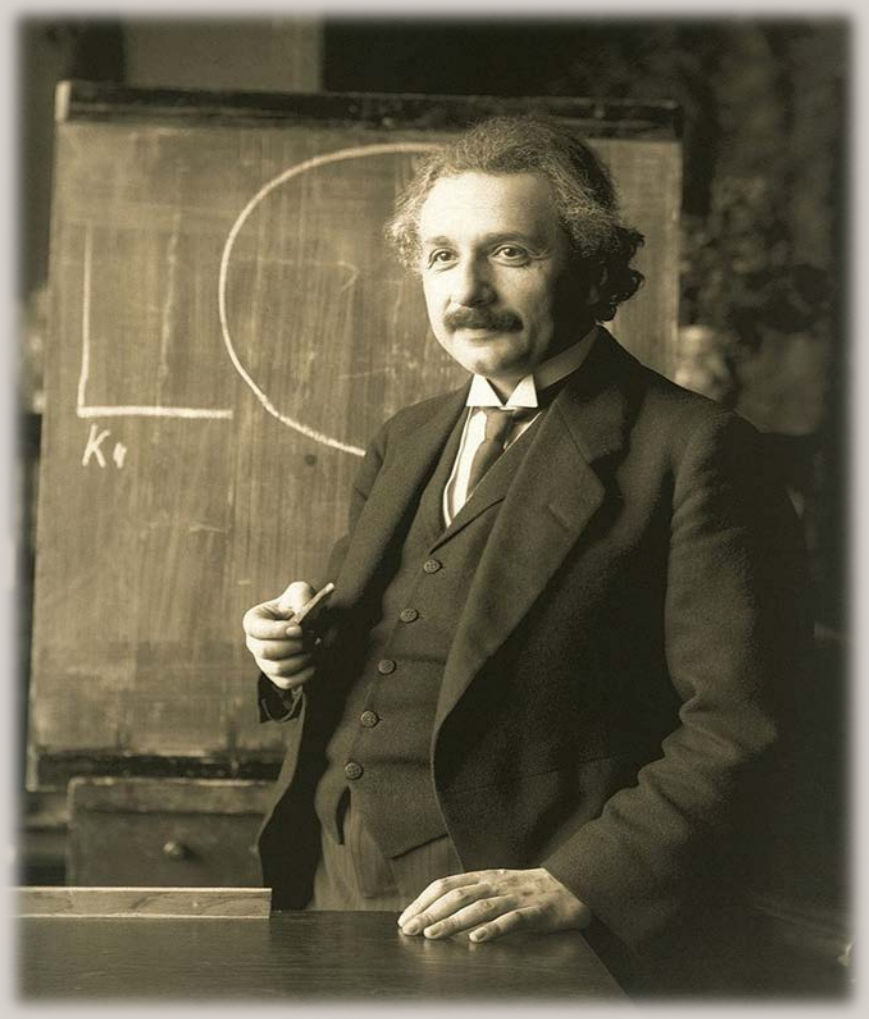
Where,

$G_{\mu\upsilon}$ - Einstein tensor

$\Lambda$ - Cosmological constant

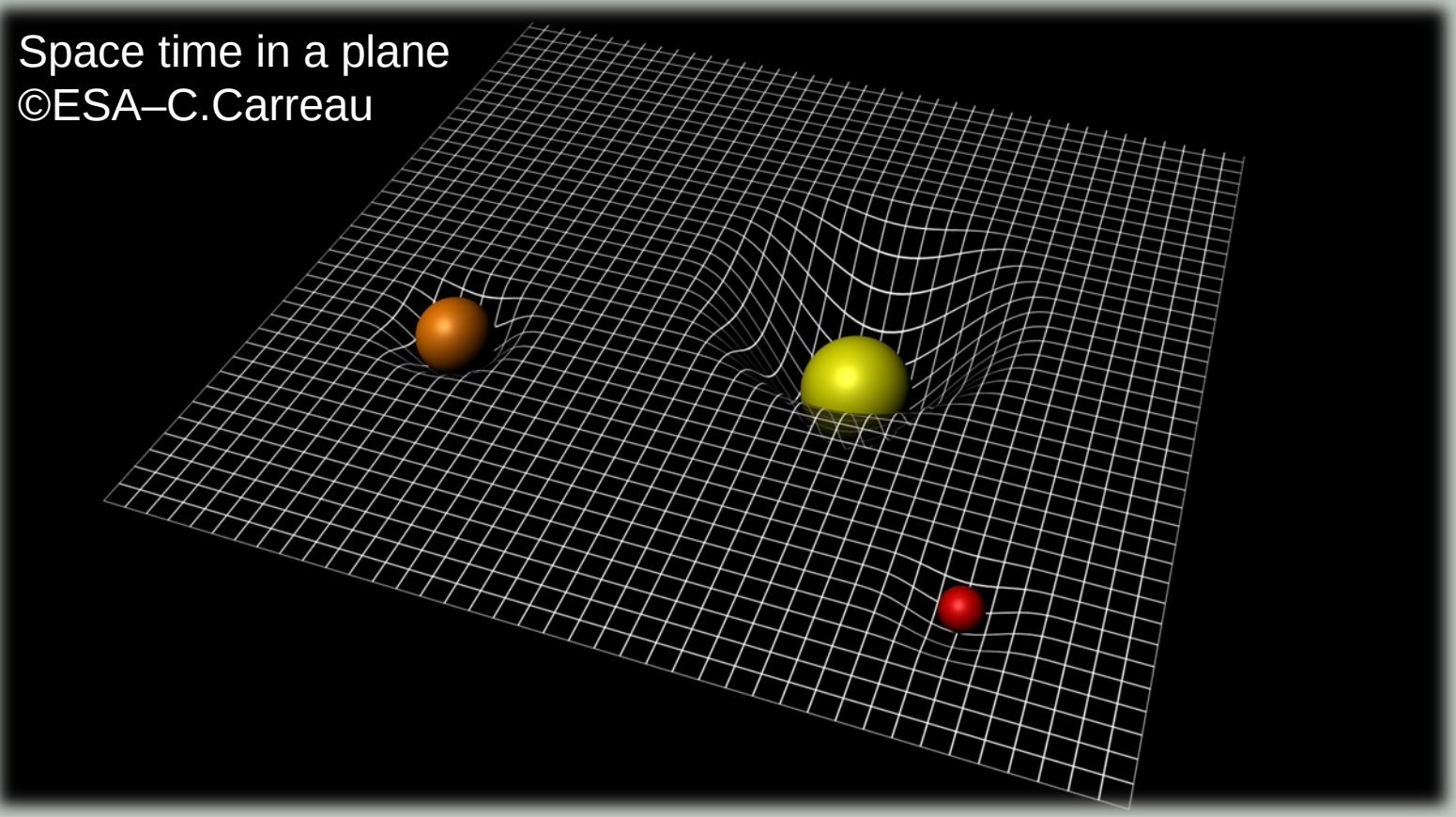
$g_{\mu\upsilon}$ - Metric tensor

$T_{\mu\upsilon}$ - Stress–energy tensor

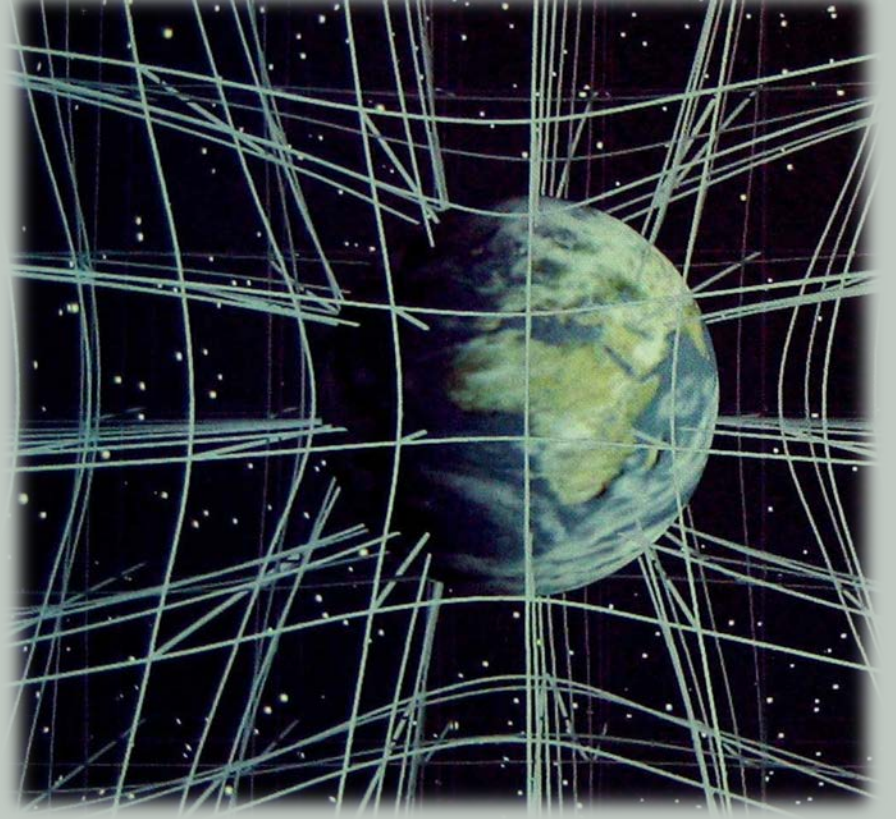


# 02 Spacetime

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



Space time in a plane
©ESA–C.Carreau



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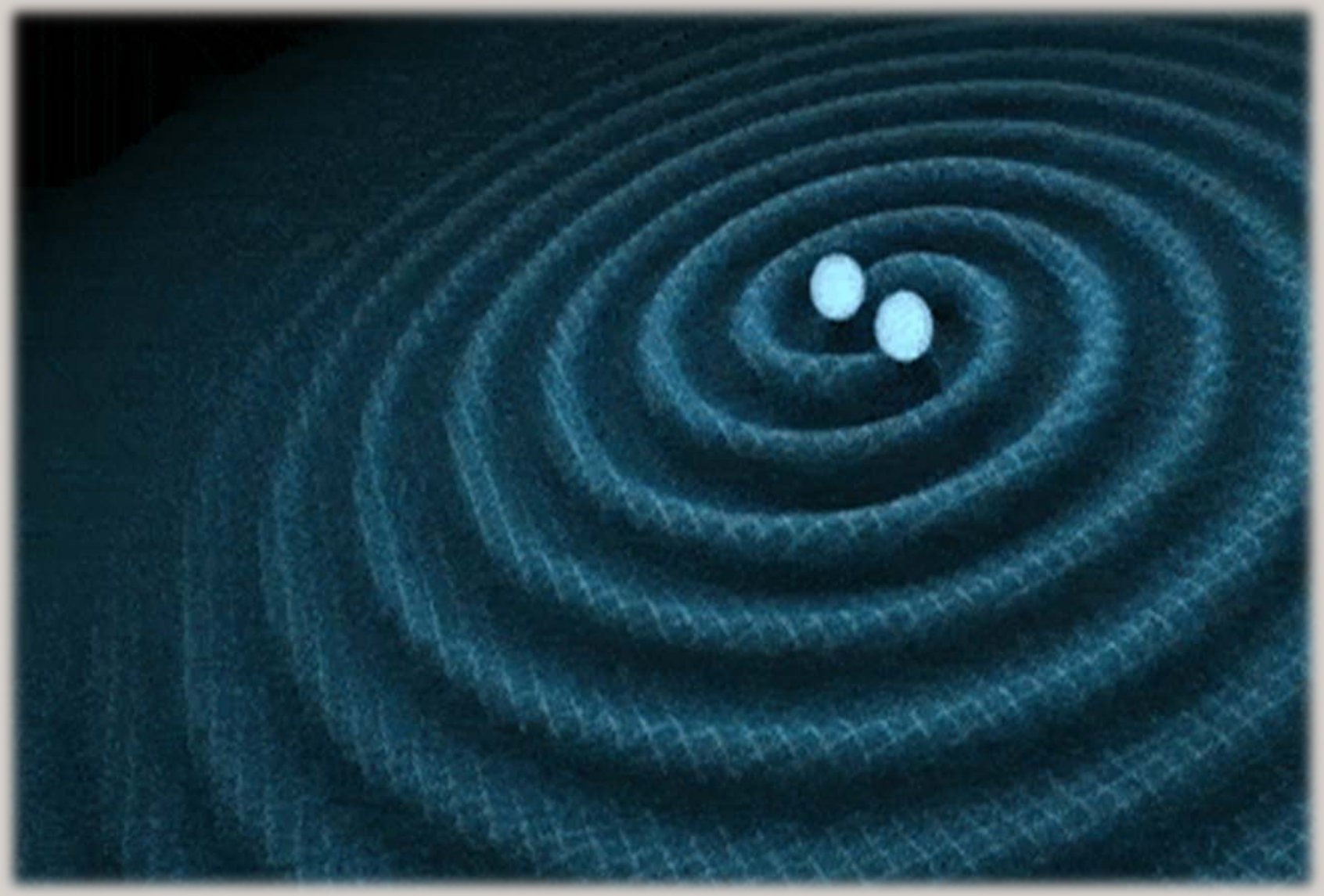
Free-falling objects are moving along locally straight paths in curved spacetime called geodesics.

# 03 Gravitational Wave



Space time in a plane
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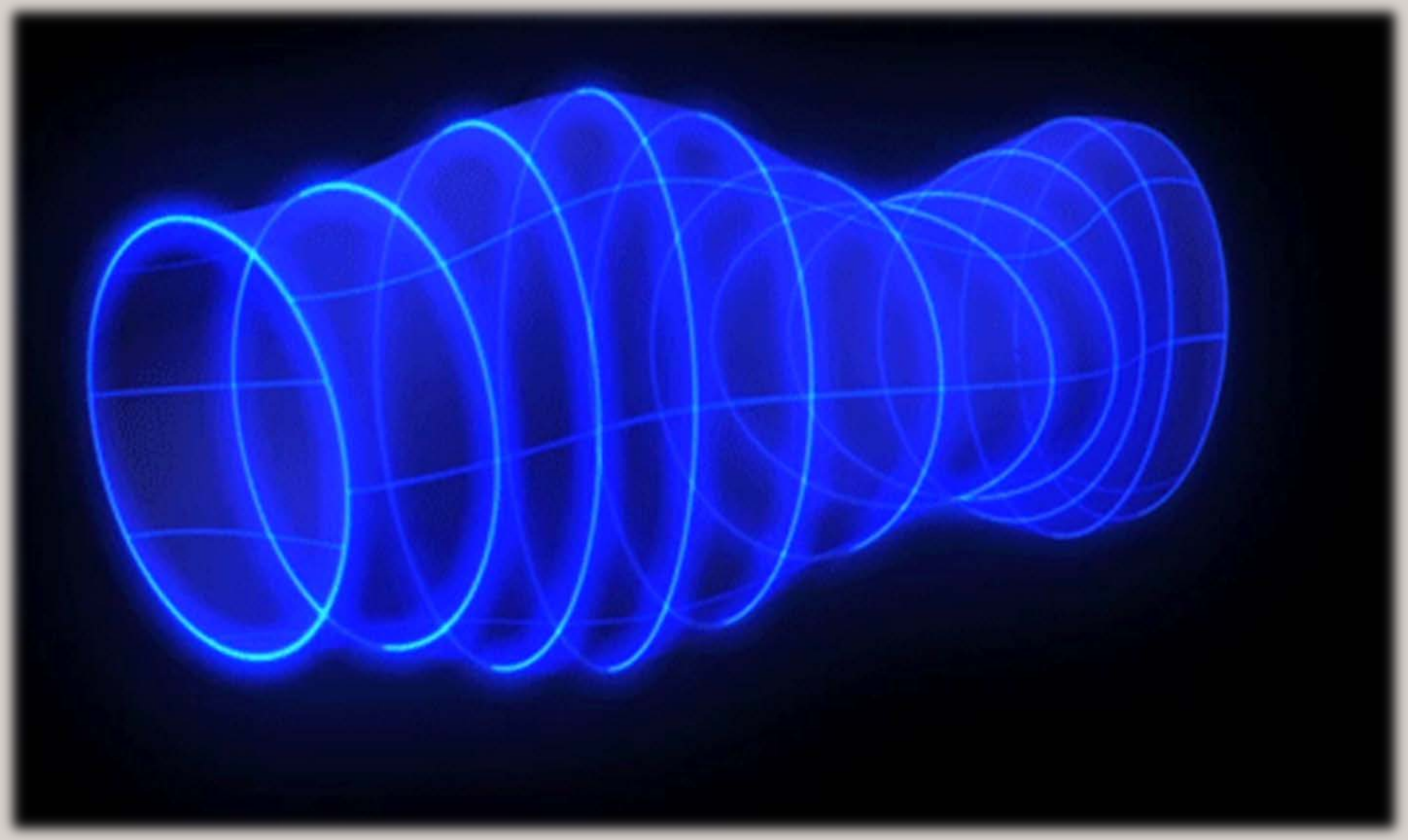
# 03 Gravitational Wave



Spacetime
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# 04 Characteristics of GW

A. 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

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

C. Propagates with the speed of light

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

E. Gravitational waves will show us details of the bulk motion of dense concentrations of energy or matter

# 05 Detection Method

Ground-Based Laser Interferometers:

A. Laser Interferometer Gravitational wave Observatory. (LIGO)

B. 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)
- LIGO is in United States and is taken care by Caltech.
- 2 LIGOs : LIGO Hanford  and LIGO Livingston
- Each arm length : 4Km

LIGO Hanford
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LIGO Livingston
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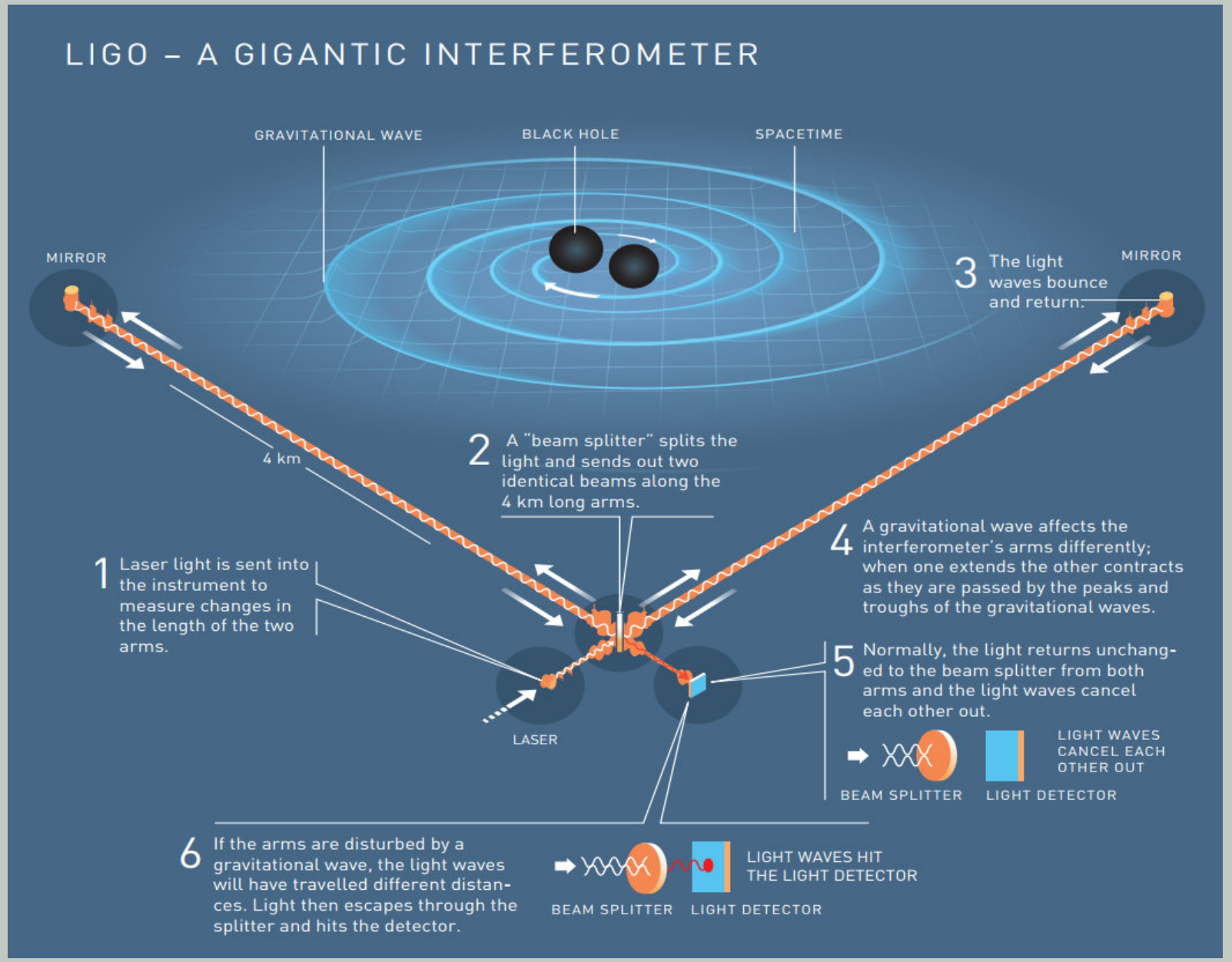
# 06 Working of LIGO



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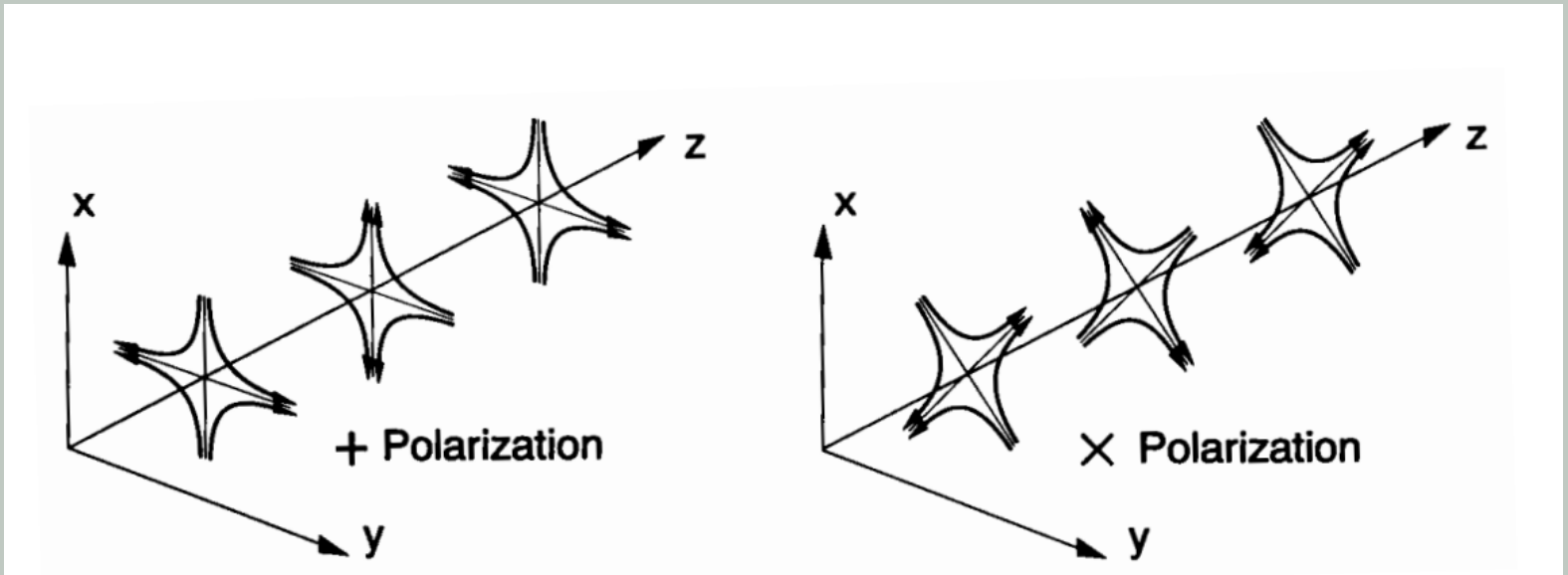
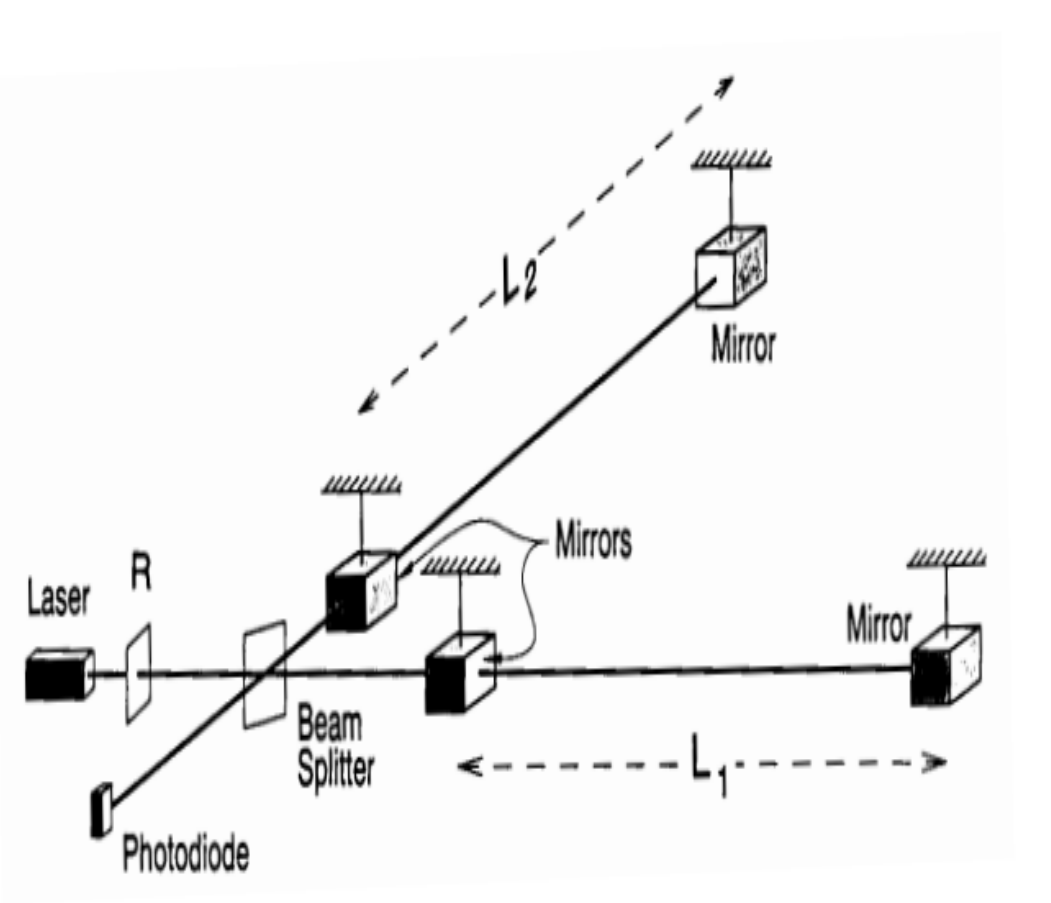
# Working of LIGO




The lines of force associated with the two polarizations of a gravitational wave.
©LIGO

# 06 Working of LIGO




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,

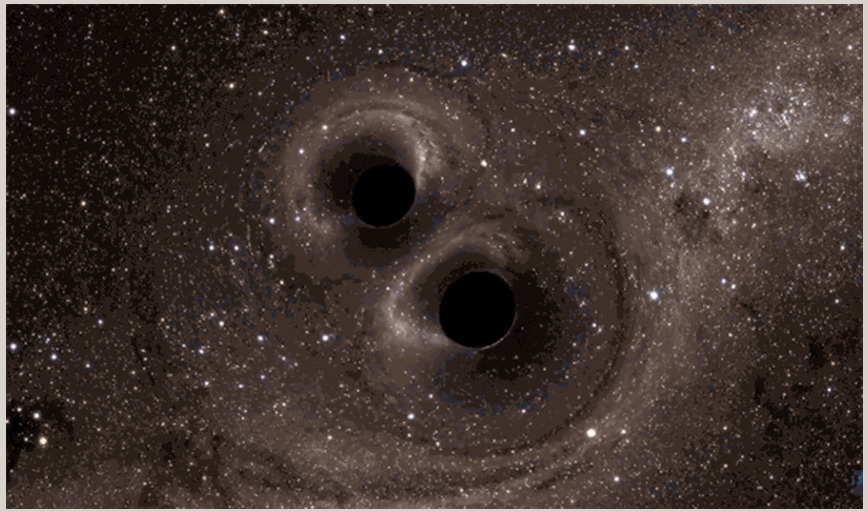
1. $\Delta L = L1 - L2$ (Change in arm length)
2. $h(t)$ is gravitational wave strain
3. Here two fs are the coefficients.

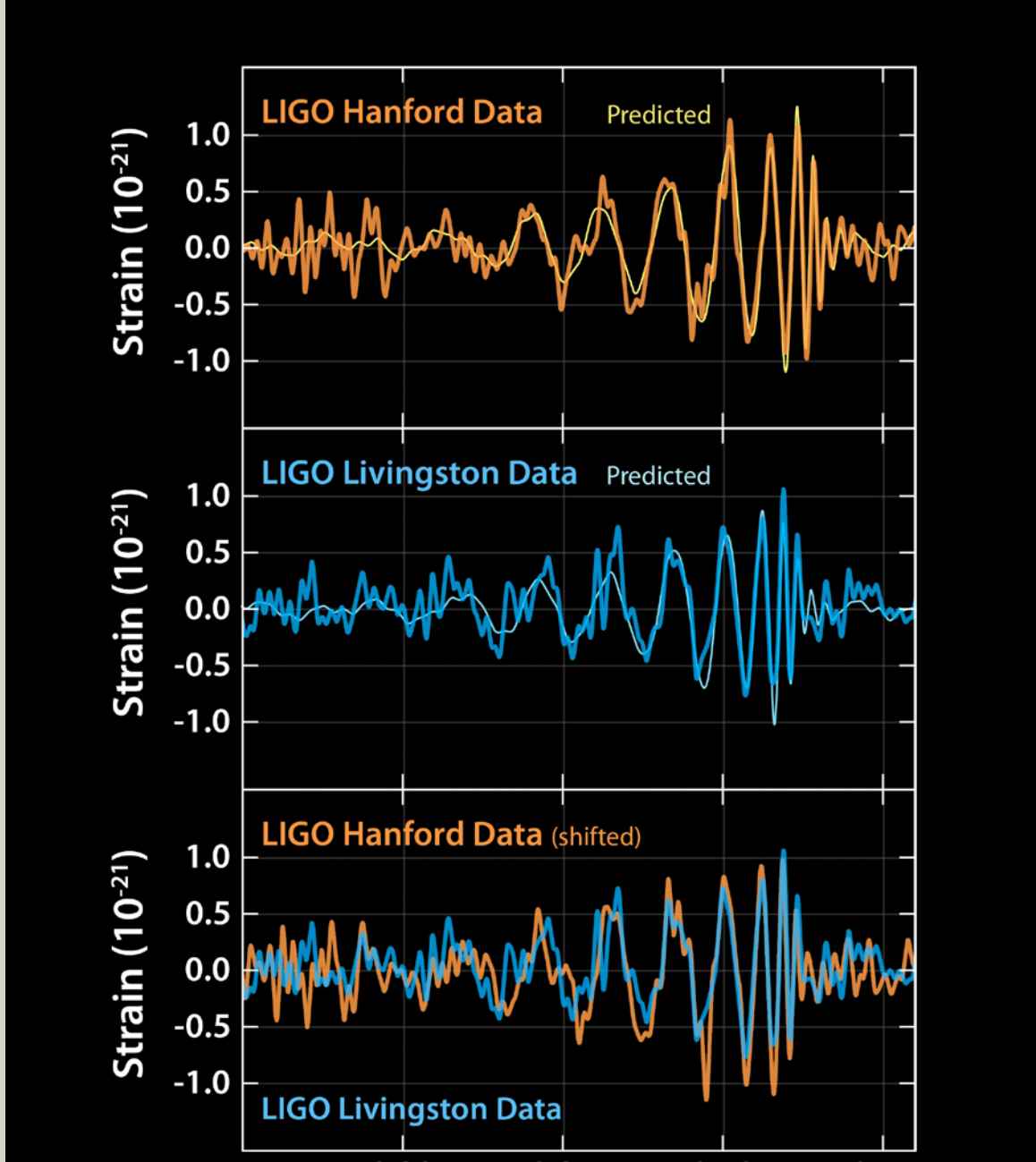
© Gravitational Waves, Kip S. Thorne

# 07 Detection

First observation of gravitational waves:

A. On 14 September 2015
B. GW150914
C. From 1.3 billion light-years away
D. $29M_o + 36M_o = 62M_o + 3M_o$ (equivalent energy radiated as GW)






LIGO Detection
©LIGO

# 07 Detection

GW170814

LIGO Detection
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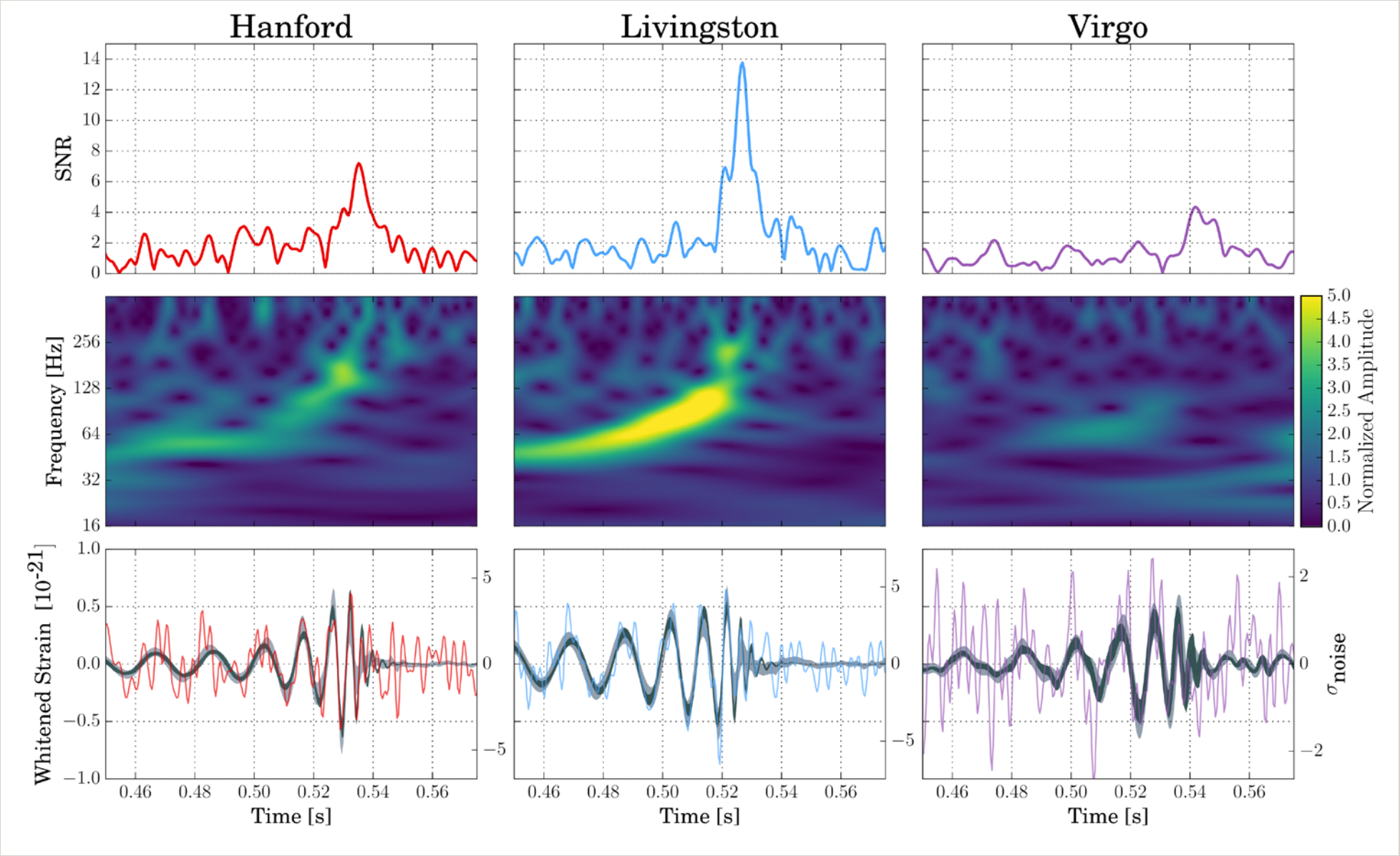

# Summary

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