Gravitational Waves - Seminar

Namburi GNVV Satya Sai Srinath(B150843EC)
Electronics And Communication Engineering
NIT Calicut

February 21, 2019

Introduction

It all started with

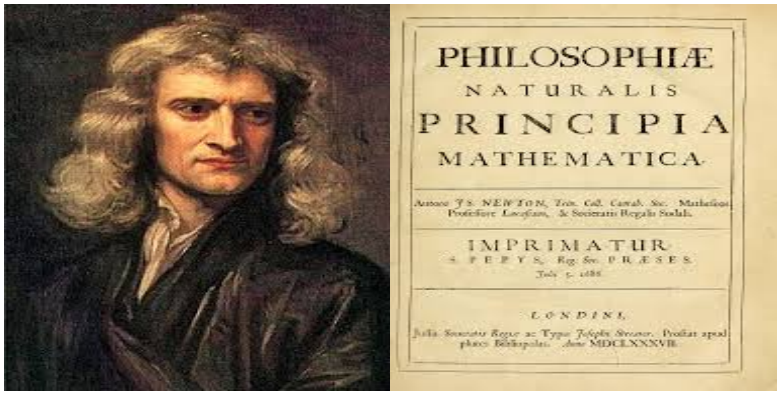

Figure: Sir Issac Newton and the famous book "Principia Mathematica"

- Forces between objects acts without any physical contact
- Travels with infinite speed, i.e information about the change in position of an object is known instantaneously in any part of universe
- When questioned how it works, Newton's reply was "Hypotheses non fingo"
- Gravity - Force of attraction between two objects

Introduction

And then ...

- James Clerk Maxwell - Unification of electricity and magnetism

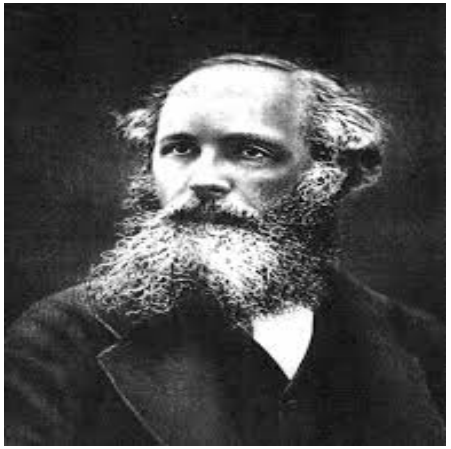

Figure: James Clerk Maxwell

- Said they both travel as a field i.e Electromagnetic field with speed of light
- Can gravity be thought something similar to that?

Introduction

Finally ...

- 1905 - Albert Einstein - Special Theory Of Relativity
  1. The laws of physics are same for all inertial/ constant speed frames
  2. Speed of light is same for all observers irrespective of their velocity

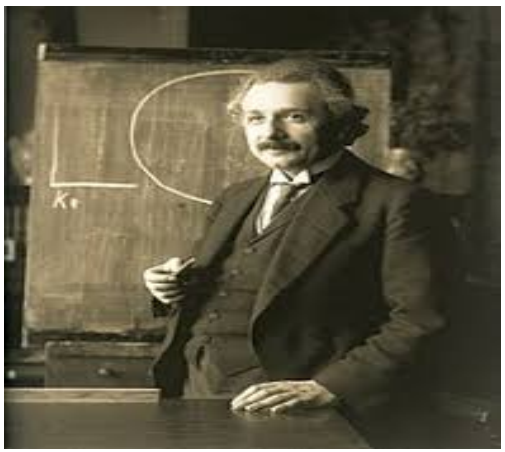

Figure: Albert Einstein

- Nothing can travel faster than light

Time dilation

- Clocks tick slower when placed in moving objects. More the velocity, slower it will tick

$$\Delta t' = \frac{\Delta t}{\sqrt{1-\frac{v^2}{c^2}}}$$

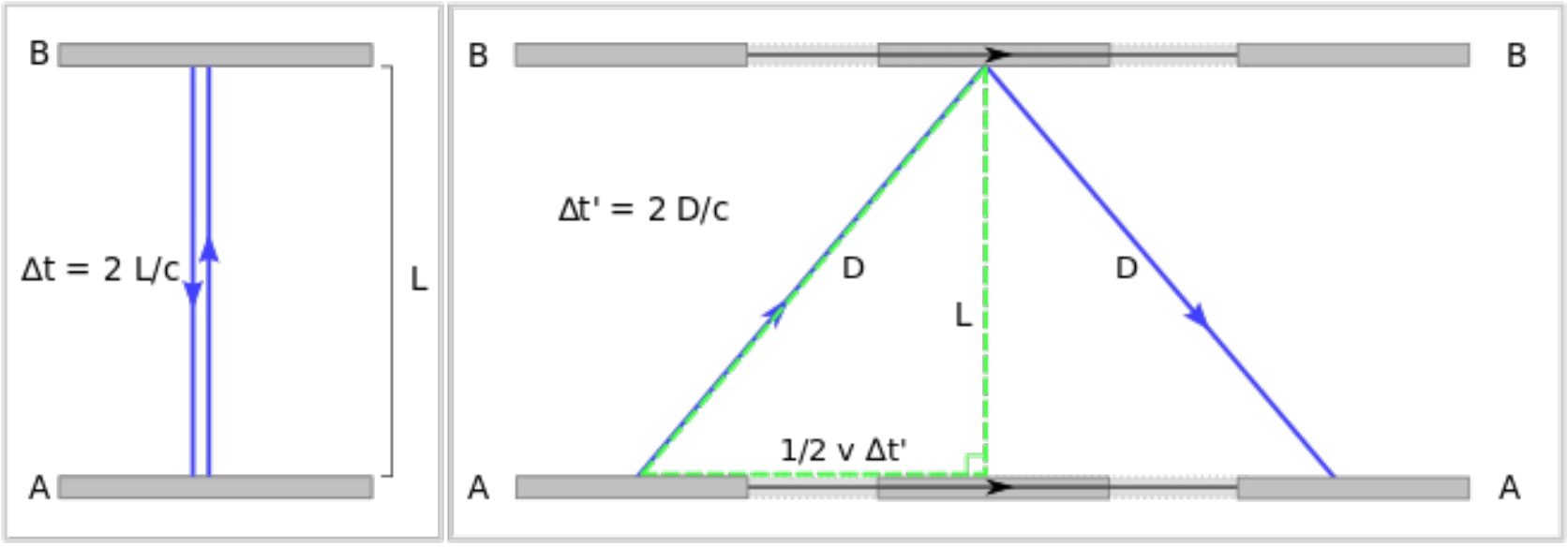

Figure: Time dilation explained. Source: Wikipedia

Hafele-Keating experiment

- Four cesium clocks are placed in commercial flights and are travelled around the globe twice
- Time in plane clocks tick slower confirming Einstein's special theory of relativity

Figure: Hafale and Keating with the apparatus. Source: Wikipedia

Principle of Equivalence

- All the masses irrespective of their nature and composition fall at the same rate in gravitational field
  Eg: Person on earth feels same as person in outer space falling with $9.8\text{m}/s^2$

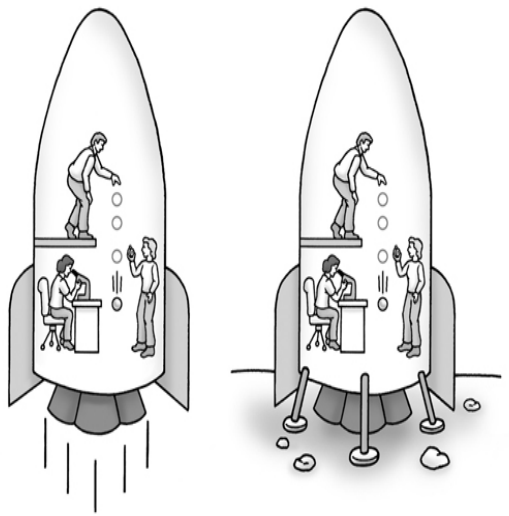

Figure: Principle Of Equivalence. Source: Dummies

General Theory Of Relativity

- Assumes gravitational field as a fabric of space-time and this 'so-called' movement of objects which change the field is known as 'Gravitational waves'
- Gravity - Consequence of mass influence over space

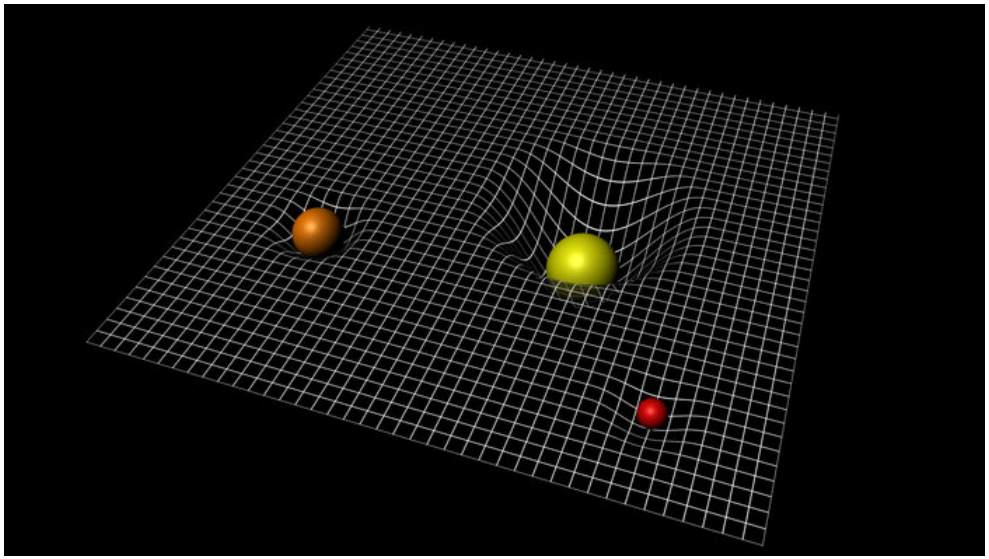

Figure: Example illustration of space-time curvature. Source: Wikipedia

Effects explained

- Gravitational lensing

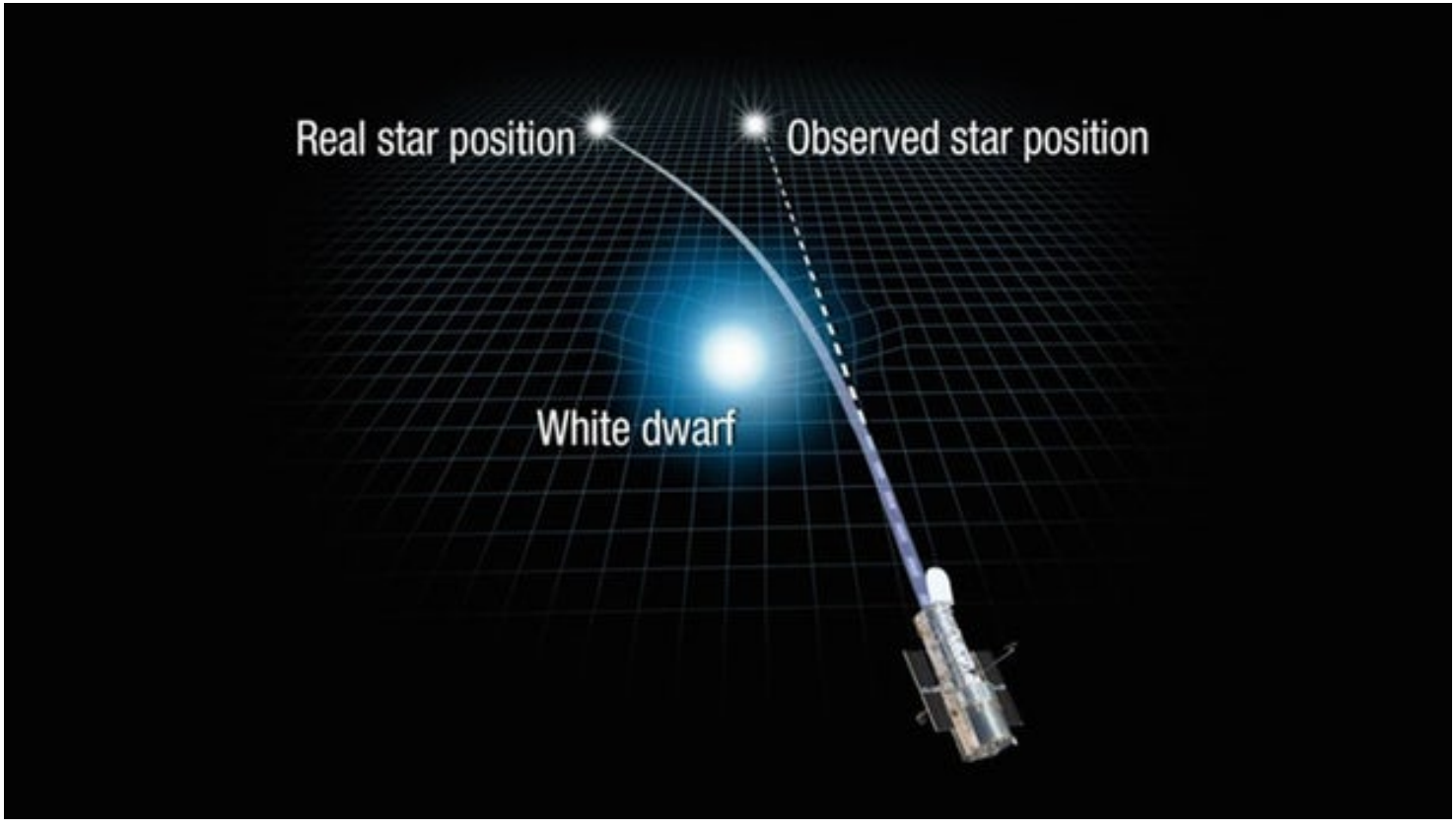

Figure: Due to warping of space by mass, light has deviated from its path which may mislead its position. Source: Wikipedia

Effects explained

- Gravitational redshift

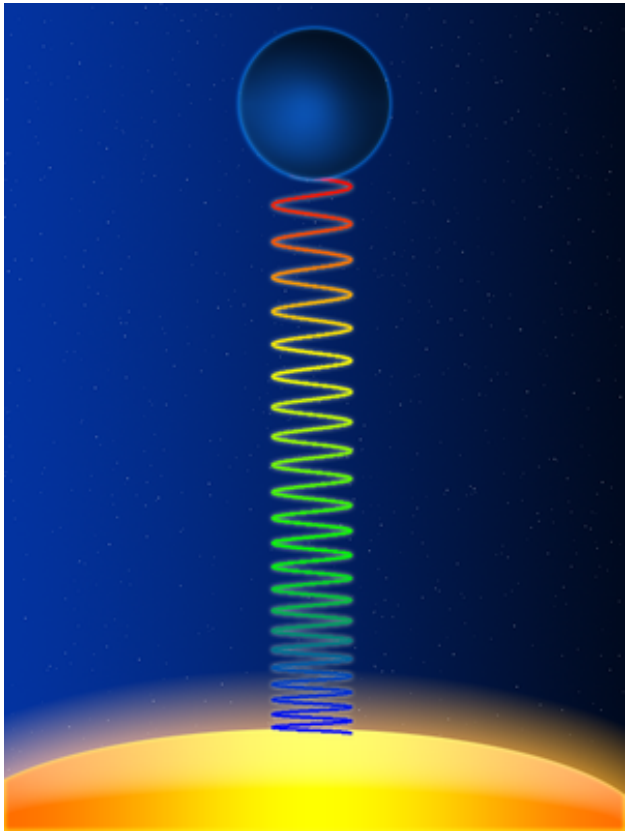

Figure: Light near the massive is blue while shifts to red at the less massive place. Source: Wikipedia

Challenges

- The effect of gravity is weakest among the four
- The most strongest gravitational wave makes a displacement of 10^{-18} meters i.e roughly 1000 times smaller than diameter of proton
- Strongest will be produced by the heaviest ones in universe

LIGO

- Laser Interferometer Gravitational Observatory
- Initial construction completed in 2002. No detection till 2010
- Renovated and modernised for 4 years
- Detected immediately after turning on in 2015

LIGO

- The normal ones

Figure: Las Cumbres Observatory. Source: Wikipedia

LIGO

Figure: LIGO observatory located at Livingston, US.
Source:LIGO/Caltech/MIT

Principle

- Uses the property of Gravitational waves i.e when it passes through an object, it expands and contracts the object in perpendicular directions and vice versa till the wave passes the object.
- This inspired in the unconventional shape of the observatory

LIGO

Figure: LIGO observatory located at Hanford, US. Source: LIGO/Caltech/MIT

LIGO

Figure: A third detector VIRGO in Italy, Europe collaborated with LIGO to improve authenticity of collected data. Source:VIRGO

Experimental setup

- Mirrors

Figure: Test masses used in arms. These will be hanging at the end of the arms. Source: LIGO/Caltech/MIT

Experimental setup

- Laser
  1. Absorption
  2. Spontaneous emission
  3. Stimulated emission

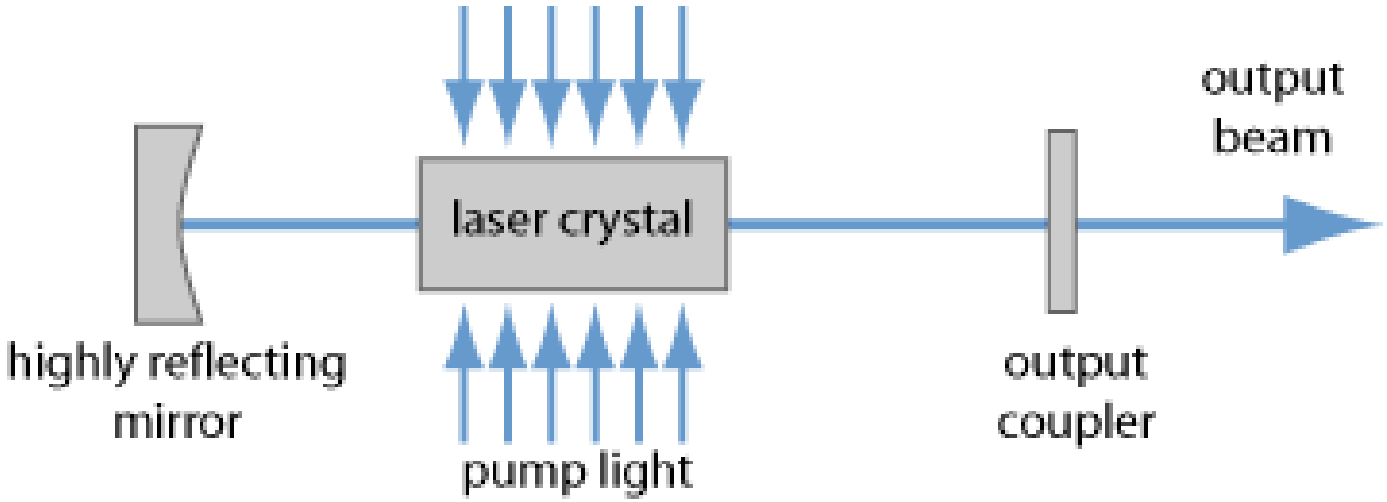

Figure: Principle involved in laser

Experimental setup

- Laser room
  1. Non planar Ring Oscillator(NPRO)
     Output - 2W, 808nm
  2. Master Oscillator Power Amplifier(MOPA)
     Output - 35W, 1064nm
  3. High Power oscillator(HPO)
     Output - 200W, 1064nm
  4. Feedback systems

Experimental setup

- Damping systems
  - Active damping system

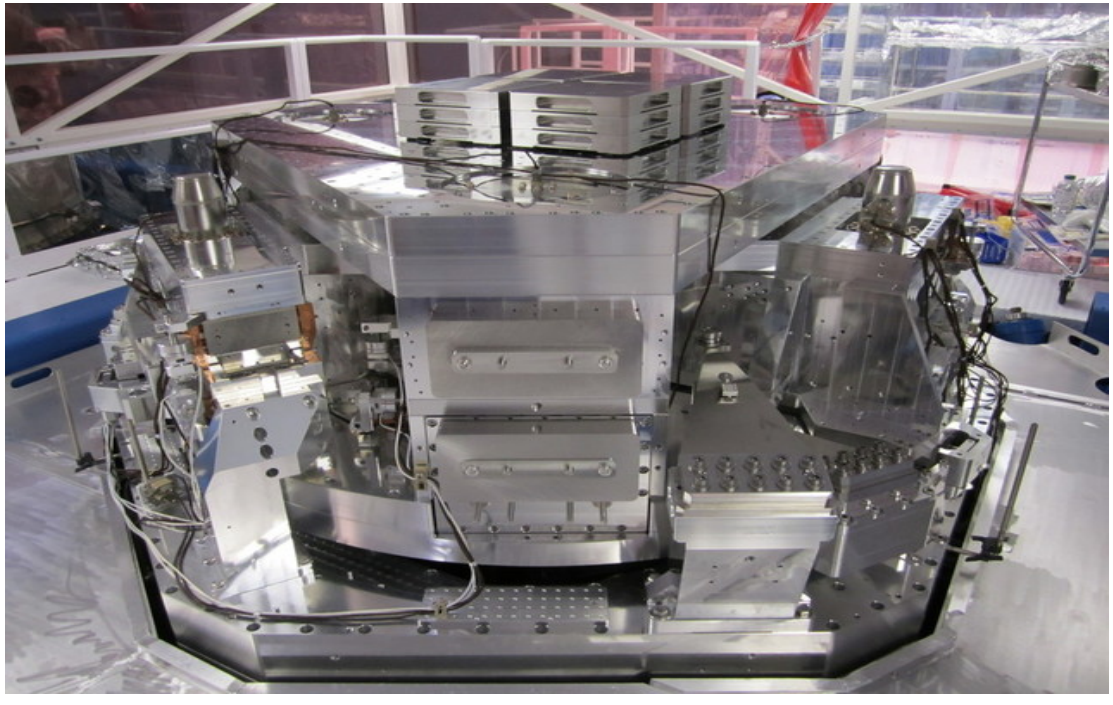

Figure: ISI system. LIGO's test-mass suspension systems hang below these 'active' isolation platforms. Source: LIGO/MIT/Caltech

Experimental setup

- Damping systems
  - Passive damping system

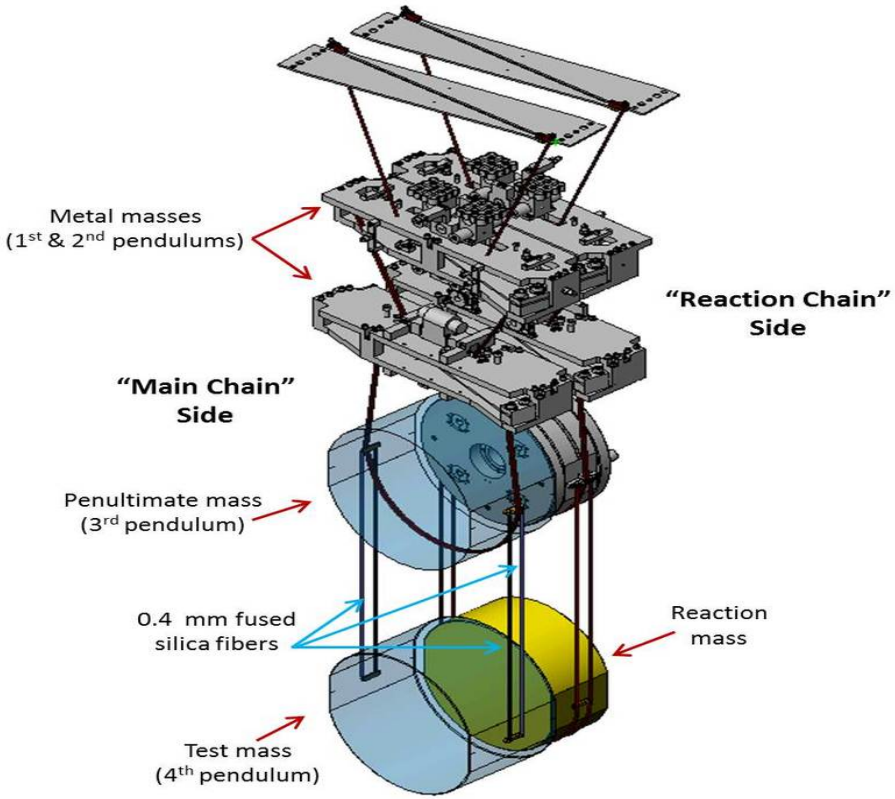

Figure: Quad system which hangs and holds the 2 test masses perfectly still. Source: IGR, University of Glasgow

LIGO in figures

- Second largest vacuum tube after the LHC
- 1200 scientists from 20 countries
- $620million till 2015
- Data equivalent to 1-million DVD
- 178 thousand DVD equivalent data produced each year
- Caltech archive has 4.5Petabyte data
- Most stable laser
- Most sensitive devide made by mankind

Nomenclature

Pair of characters (like AABBCCDD) where

- The first one(AA) indicates the nature of wave
- Second pair(BB) describe the year
- Third pair(CC) tells about the month
- Fourth pair(DD) tells about the date of discovery

Supernovae

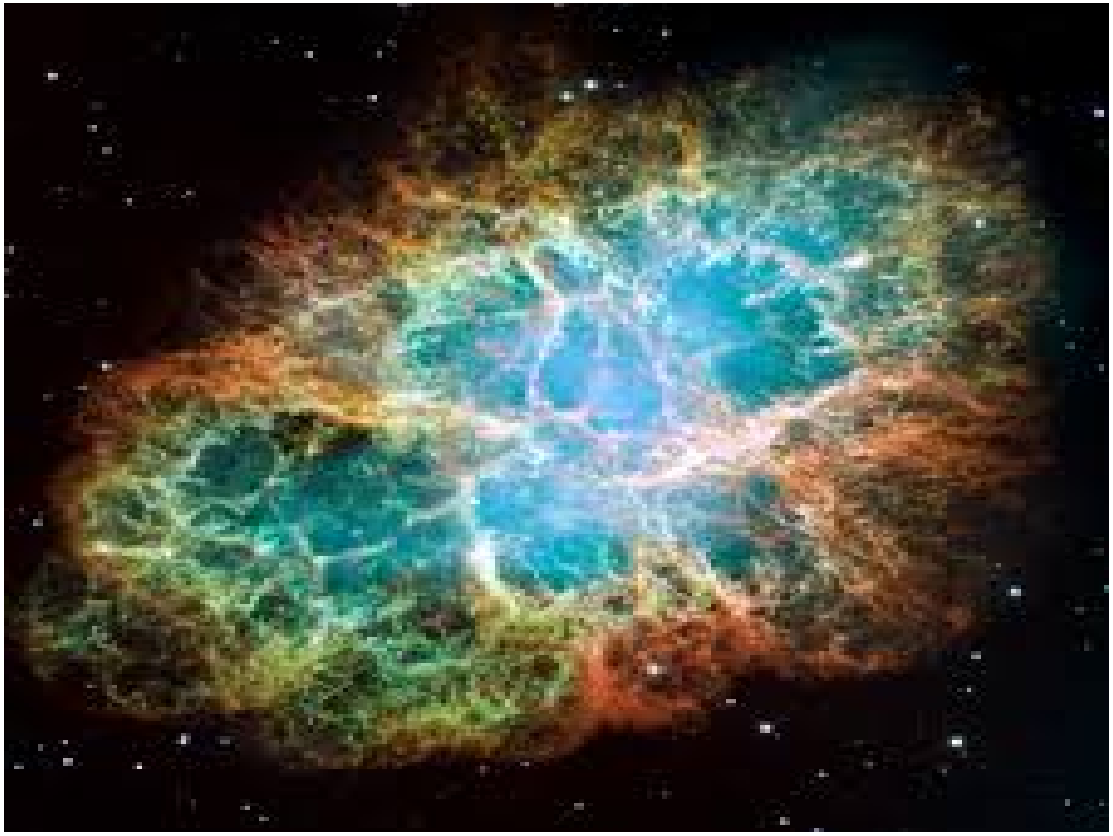

Figure: An artist depiction of Supernovae. Source: Wikipedia

Neutron star

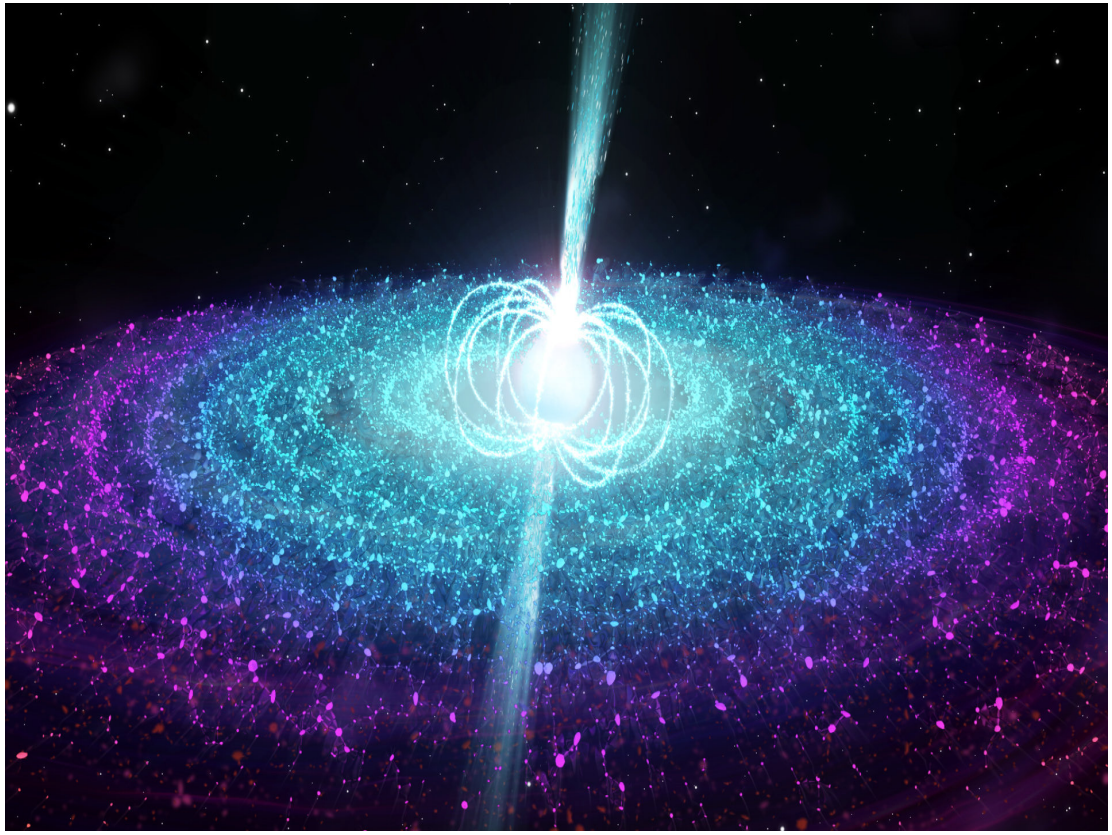

Figure: An artist depiction of Neutron star. Source: Wikipedia

Celestial bodies

- White Dwarf
  - Mass of Sun and radius of earth
- Black Hole
  - Event Horizon
- Binary system
  Eg: Mizar and Alcor in Ursa Major

Notable detections

- GW150914 - Binary black hole merger

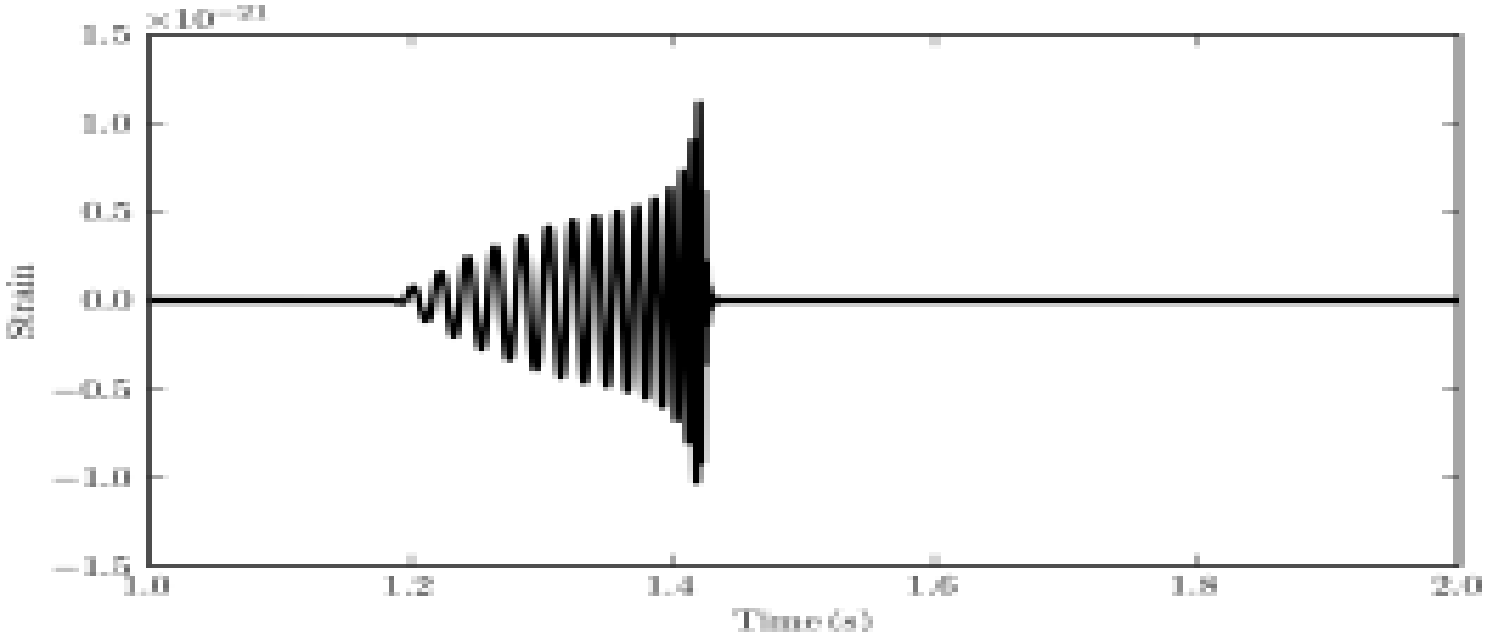

Figure: Waveform interpreted due to merge of binary black hole. The strain increases with time and reaches its peak during merger. Source: LIGO/MIT

Discoveries

- GW170817 - Binary neutron star merger

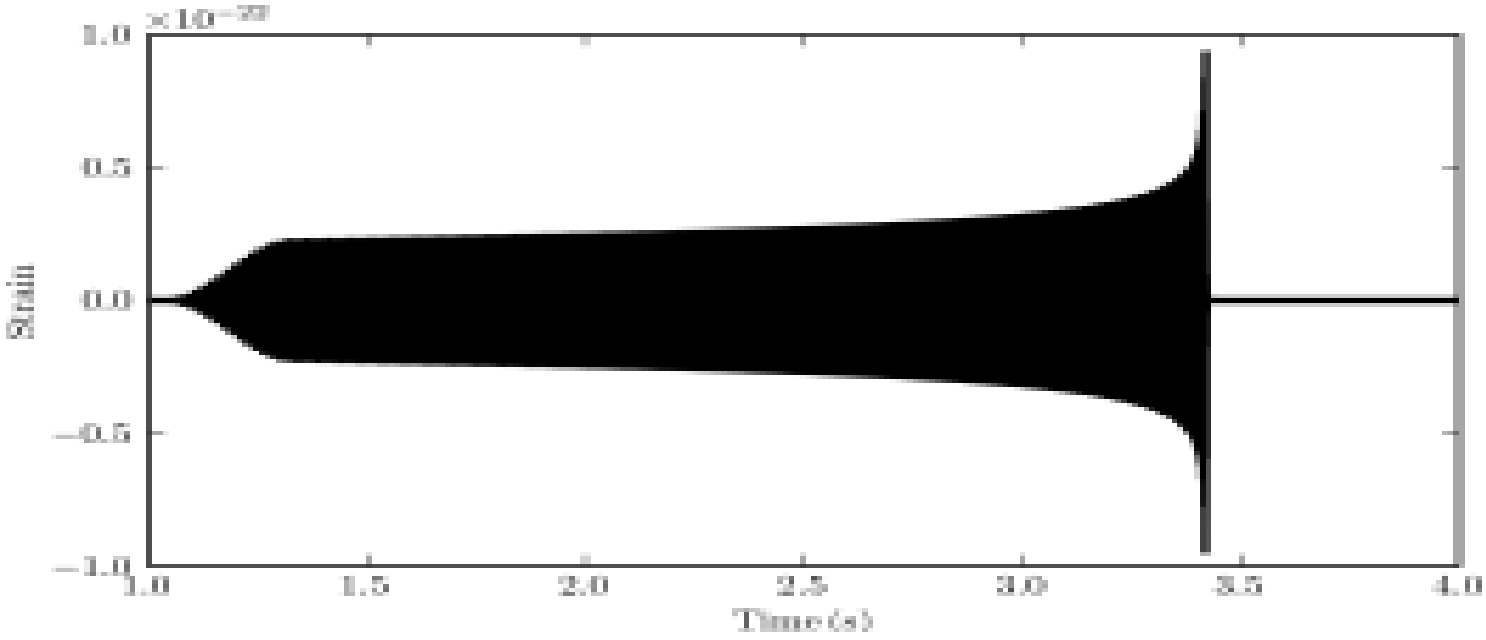

Figure: Waveform interpreted due to merge of neutron star. Strain maintains a constant value post merger and suddenly reaches maximum. Source: LIGO/MIT

Contributors

Figure: Kip Thorne, Rainer Weiss and Barry C.Barish awarded the Nobel Prize for Physics, 2017

Uses

- A new tool to observe the universe
- Know more about core of stars, black holes where EM waves can't enter/escape
- Triangulation techniques, Lensing effects to be applied to know the exact position of galaxies
- Doppler shift techniques can be applied to know the velocity, size, mass of the sources

Uses

What about technology?

India in LIGO

- Contributions
  1. Experimental setup and development of detectors
  2. Formulation of shape of waves that are likely to observe
  3. Data Analytics
- INLIGO in Maharashtra, India by 2024

Any questions..?

Thank You!!