Gravitational Wave Astronomy

1 Introduction

In Einstein's general theory of relativity, gravity is treated as a phenomenon resulting from the curvature of spacetime(caused by the presence of mass). As massive bodies move about in space, this curvature changes in order to reflect the change in positions of the bodies. In some of the most violent and energetic processes in the Universe, accelerating objects generate changes in this curvature, which propagate outwards at the speed of light in a wave-like manner. These propagating phenomena are known as gravitational waves(GW). Some of the sources are binary systems of black holes, neutron stars and white dwarfs; and events such as supernovae. The spacetime itself gets distorted owing to strain caused due to propagation of GW.

2 Detection of GW

2.1 Indirect Detection

The first instance was the discovery of a new type of binary pulsar discovered by Hulse and Taylor (Nobel Prize 1993). After observing the system for several years it was found that the orbit period is declining: the two astronomical bodies are rotating faster and faster about each other in an increasingly tight orbit. Though the change is small, it is measurable. This decrease in the orbital period was presumed to occur because the system is emitting energy in the form of gravitational waves in accordance with what Einstein in 1916 predicted should happen to masses moving relatively to each other. Further observations showed that the observed change in the orbital period matches the prediction from gravitational radiation assumed by general relativity to within 0.2 percent. This can be seen as the **first indirect proof of the existence of gravitational waves**.

2.2 Direct Detection using LIGO and VIRGO

LIGO stands for Laser Interferometer Gravitational-wave Observatory. As the name suggests, at their cores, LIGO's interferometers are Michelson Interferometers.

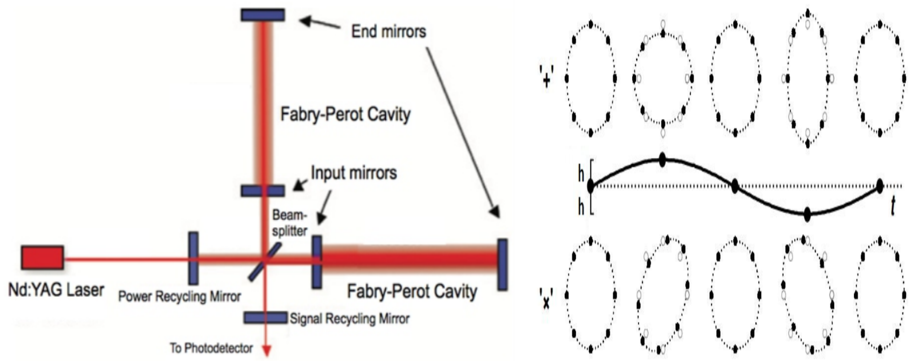

Figure 1: (i)An oversimplified schematic of the optical layout of the LIGO interferometers. (Credit: RRCAT) (ii)Illustration of the space-time distortion caused on free floating bodies by plus and cross polarised GW

The 4km-long space comprises the Fabry Perot cavity. After entering the instrument via the beam splitter, the laser in each arm bounces between its two mirrors about 300 times before being merged with the beam from the other arm. These reflections serve two functions:

- It builds up the laser light within the interferometer, which increases LIGO's sensitivity (more photons also makes LIGO more sensitive)
- It increases the distance traveled by each laser from 4km to 1200km hence allowing us to measure change in distances 10,000 times smaller than a proton

As laser power enters the interferometer, the power recycling mirror reflects the laser light that has traveled through the instrument back into the interferometer (hence 'recycling'). This process greatly boosts the power of the laser beam inside the Fabry Perot cavities without the need to generate such a powerful laser beam at the outset. Thus, power recycling mirror helps to increase laser power which results in sharper fringes thereby increasing the interferometer's resolving power.
The undulations in spacetime cause the length of the perpendicular arms of the interferometer to vary differentially, one arm decreases in length and the other arm undergoes elongation. This variation results in a new interference pattern which can be used to determine the properties of GW and its sources.

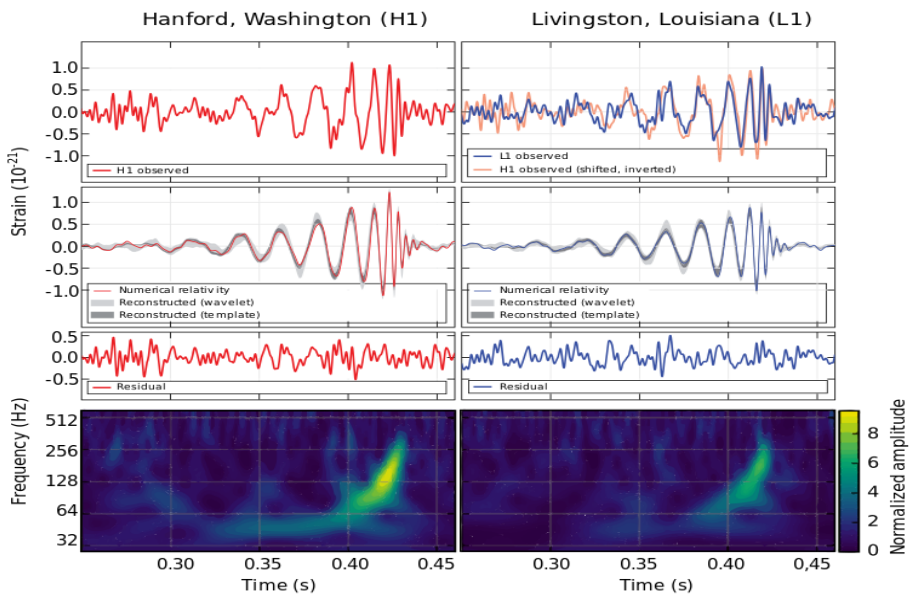

Figure 2: LIGO measurement of gravitational waves(signal GW150914). (Credit: B. P. Abbott et al.)