An Overview on Gravitational Waves and its Propagation

Dr Shailendra Kumar Srivastava
Associate Professor

Dr Subhash Kumar Sharma
Assistant Professor

Department of Physics
MGPG College ,Gorakhpur

Abstract

Gravitational Waves are a new form of energy that is too sensitive to measure. The study of Gravitational Waves paves a unique way to approach the new era of universal science. It is quite interesting to note that experimental proof of the early theory of Einstein is successfully proven after many years. The paper tells about the concepts of Gravitational Waves, propagation of Gravitational Waves, its effect on objects on Earth and various factors that affect the measurements along with their method of approach to detect Gravitational Waves. Detecting Gravitational Waves is a tedious process and it requires a very highly sensitive experimental setup to carry out the detection as well as on considering the current trend of technology it is observed that detection faces massive limitations. Detection of Gravitational Waves opens up a new way for understanding supermassive binary systems such as neutron stars and black holes and also for studying on Early universe history.

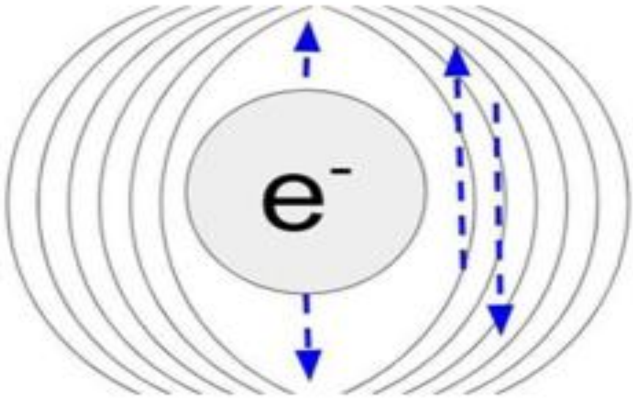
Keywords: LIGO,Virgo, Gravitational Waves, Black Hole Collision, Neutron Star Collision.

INTRODUCTION

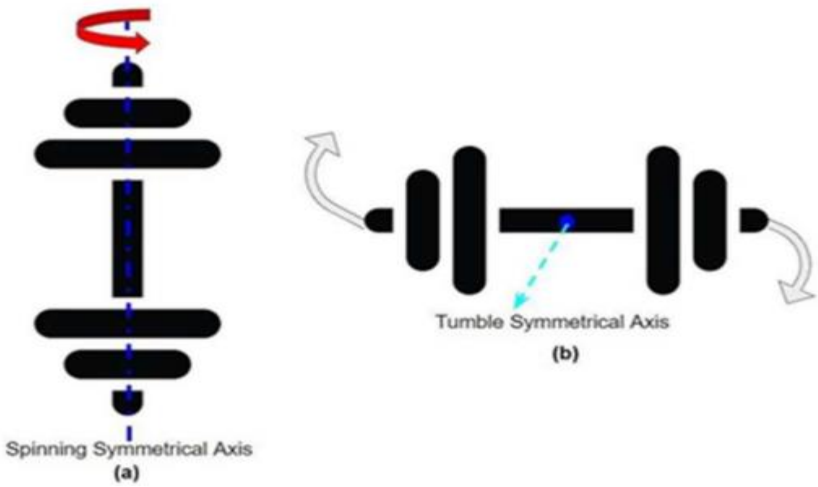
Albert Einstein's General Theory of Relativity predicted the Gravitational Waves[13] nearly a century ago, the existence of Gravitational Waves was first demonstrated in 1979 [12]. By observing a binary system composed of a pulsar orbiting a neutron star for which Hulse and taylor were awarded Nobel prize for physics in 1993 [1], but we detected it only at recent times, This time gap is mainly due to the development of experimental setup technologically, even though the main principle behind the detector is very simple, it took almost a decade to prove the existence of Gravitational Waves. Since these waves are coming from very distant galaxies which are many million light years away from us, the waves eventually become very small for measuring when it reaches us, but somehow with the use of cutting edge technology we made detection of Gravitational Waves a reality. Which won the Nobel prize in physics for Rainer weiss, Barry C. Barish and Kip Thorne . In order to prove the thesis and to open a new era in the field of Astrophysics, the world scientist worked together to observe the existence strength of Gravitational Waves. In order to understand the detection of Gravitational Waves (GW) we first have to completely analyse the formation, propagation and effects of GW. Furthermore, let's start the discussion from the basics of formation of GW. It is predominantly important to know the basic principles behind the detection of Gravitational Waves and also the limitations that approach at the time of detection and consolidation. LIGO and observatories work precisely in the field of detection of GW. Such observatories made several historical observations of collision. The infrastructure of observatories also play a vital role in terms of accuracy and sensitivity. Optimisation of infrastructure is also a key factor to obtain a refined result.

FORMATION AND PROPAGATION OF GRAVITATIONAL WAVES

Albert Einstein's General Theory of Relativity shows the nature of gravity as a kind of geometry of space time Curvature, it also tells that the fabric of space time can be dragged, stretched, distorted and warped by matter. supermassive accelerating objects such as black holes or neutron stars can drastically alter space time in which Gravitational Waves are produced, not only supermassive systems even oscillation of subatomic particles can also cause a Gravitational Waves which will be extremely small and practically impossible to measure. We all know that an oscillating charge such as an electron radiates energy in the form of an Electromagnetic wave which is directly proportional to the frequency of oscillation. Likewise any oscillating charge also produces Gravitational Waves which is directly proportional to its mass, but it is nearly impossible to measure Gravitational Waves produced by such particles since there mass is very low.



Fig(1) Electron oscillation and its GW propagation



Fig(2) Example of GW formation: a) symmetrical spinning, b) tumbles end to end

Fig.2a says that the dumble symmetrically spins with a symmetrical axis causing no radiation of Gravitational Waves. Fig.2b shows that the dumble tumbles over it end to end causing the radiation of Gravitational Waves. The faster the tumble occurs, the stronger is the radiation. At the same time heavier the bodies, stronger the radiation of Gravitational Waves. However Supermassive objects which are accelerating rapidly can produce Gravitational Waves [13]. Which can be detected by our current technology. Supermassive binary objects such as black hole or neutron stars orbiting each other radiate Gravitational Waves which carry some of the system's orbital energy. As a result the objects get closer to each other and increase their orbital frequency which causes them to emit Strong Gravitational Waves and continue to lose their orbital energy. After which they merge into a single system. At the time of merging the magnitude of the Gravitational Waves will be maximum. Not only binary systems, any spinning asymmetrical system or violent events such as supernovae (asymmetric) will radiate Gravitational Waves [14].

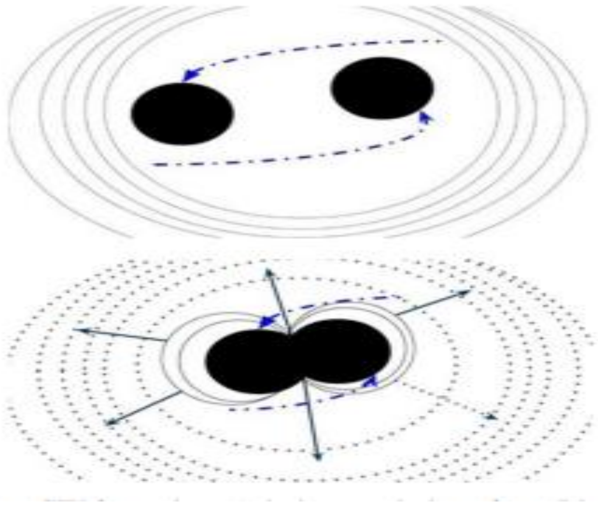
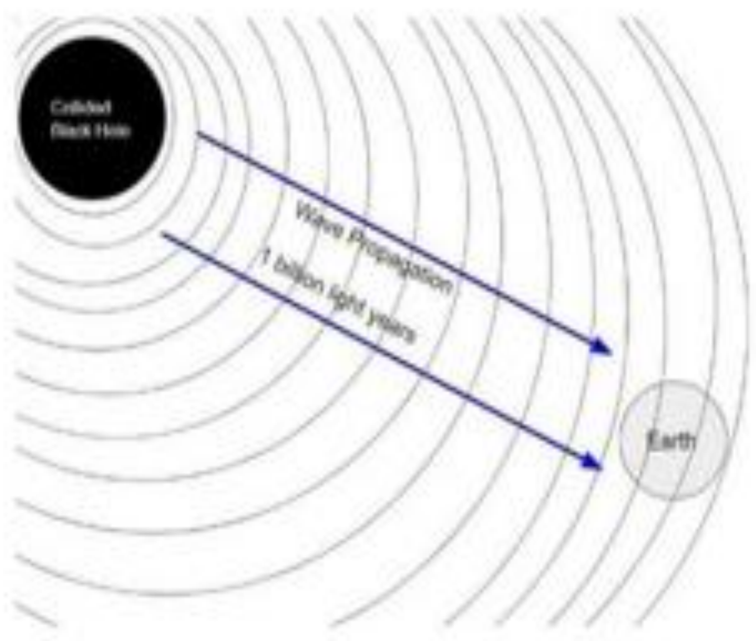


Fig. 3. GW formation: a) during revolution of two Black hole, b) massive GW formation at the time of collision

We know that a Wave is a disturbance that transmits energy from one place to another. For instance sound waves are a disturbance in air pressure, electromagnetic waves are a disturbance in electric and magnetic fields. Like these Gravitational Waves are disturbance in the fabric of space time itself. They propagate at the speed of light and transverse in nature. As they pass through any object they stretch and squeeze the object. We recently detected Gravitational Waves from two collided black holes. Since this event happened 1.3 billion light years away from us, it almost took the waves 1.3 billion years to reach Earth: Speed of light = Speed of GW. (1)



Fig(4) GW Propagation From Colliding Black Holes To Earth

EFFECTS OF GRAVITATIONAL WAVE

The propagation of Gravitational Waves (GW) over an object tends to change dimension [1]. That change in dimension is an elastic deformation that is directly proportional to the strength of the propagation waves. For an instance let us consider an imaginary rectangular block of length (l) and width (b) and the waves propagating towards the block. Consider that the wave propagation is perpendicular to this paper. The change in dimension occurs perpendicular (transverse) to the object:

Elastic Deformation ∝ Strength of GW. (2)

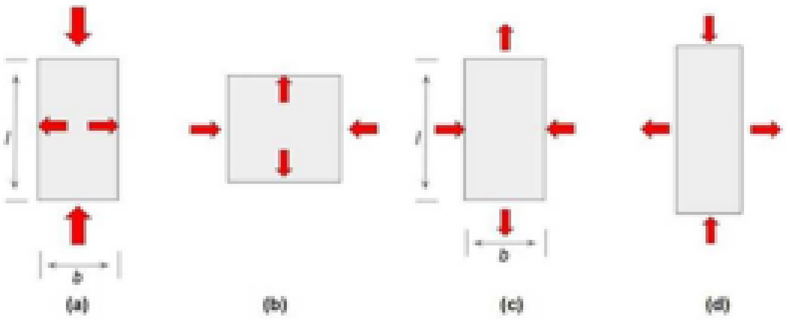


Fig.(5) Sequential effect of Gravitational Waves on an imaginary rectangular block. The arrow marks indicate the subsequent forces tend to act on the block due to GW propagation

Effect on Earth and its object present on Earth

The effect of gravitational wave propagation to Earth will surely cause an effect on all the particles on Earth including very minute and massive objects. Considering the history of the current scientific world, the Earth has not met with a GW that is adequate to cause a notable elastic deformation. With recent technology, it is noted that a GW propagation was detected and it ensures the occurrence of elastic deformation. Since the received wave is too less sensitive, there is no trace to see an elastic deformation on objects. The deformation level tends to be so negligible nearing 2.5×10^{-20} m (approx.). It is very difficult to measure the deformation as even the measuring scale also tends to undergo the same sequential change of dimension. Keeping in mind the limitation of detection and measuring, the researchers decided to come up with a detector that is most significant to detect the occurrence of GW propagation and its magnitude. In terms of effect of GW, it is concluded that there is an effect on all particles but it is negligible.

NEED FOR DETECTION OF GRAVITATIONAL WAVE

All the predictions made by General Theory of Relativity such as deflection of light, dragging of space time by spinning objects and Time dilation in gravitational fields have been physically tested and verified many decades ago except for Gravitational Waves. Detecting Gravitational Waves not only verify the General Theory of Relativity but also opens up new ways to study our universe. By detecting Gravitational Waves we can study about colliding black holes which are almost invisible to several telescopes. Detecting and analysing the information carried by Gravitational Waves allow us to observe the universe in a way never before possible. It opens up a new era in the field of astronomical research and applied science. Since the speed of GW is equal to the speed of light, the hidden events happening across the observable universe could be observed with the help of GW detection rather than conventional telescopic methods that deal with propagation of light. It ultimately serves as an alternate method of measurement to obtain the properties of black holes.

LIMITATIONS IN DETECTING GRAVITATIONAL WAVE

Amplitude, when a gravitational wave propagates from one point to another its amplitude decreases sequentially. In the case of black hole collision which takes place at a very far distance from Earth, the amplitude will be maximum at the point of collision and as it propagates and reaches us its amplitude gets decreased. This reduced amplitude is too small in order to measure or detect using any type of sensitive measuring instrument Strength, the generation of Gravitational Waves is directly proportional to mass of the object. A measurable gravitational wave is produced only if two or more massively heavier objects collide each other. When lighter objects collide each other the generated Gravitational Waves are very small to measure or detect. Instrument deformation, when a set of Gravitational Waves passes through Earth it tends to produce an elastic deformation to all objects on Earth including the measuring device. Example: a measuring scale also tends undergo a elastic deformation along the other objects on Earth, so it is impossible to measure elastic deformation of objects

DETECTION

The first Gravitational Waves detector was built by Joseph Weber in 1969. After which many sensitive detectors were built in mid-70 based on Weber's design, but no significant detection was made for many decades. Until 2015 a detector in the USA named LIGO detected Gravitational Waves from two merging Black holes. Currently there are many active detectors around the world such as LIGO, VIRGO, GEO600 and KAGRA. Which are capable of detecting Gravitational Waves of order 10-20 m (approx.). All these Detectors

FUTURE DETECTORS DEVELOPMENT

Scientists around the world work on development of Current Gravitational wave detectors. At present there are many gravitational wave detectors under research and development. In future LIGO plans to have a worldwide network of widely separated detectors which improves to locate sources of Gravitational Waves and test it. Some of the future detectors:

1. Space based detectors: some of the countries proposed to operate detectors on outer space using an array of satellites such as LISA (NASA), DECIGO (Japan), Tianqin (China),Taiji (China).

2. Land Based detectors: many ground based detectors are under Research and construction all around the world such as LIGO (India), KAGRA (Japan), AIGO (Australia), Einstein Telescope (Europe) and Cosmic Explorer

CONCLUSION

The Detection of Gravitational Waves (GW) opens up the new era in the field of Astrophysics. The historical incidents such as Black Hole Collision, Neutron Star collision and other heavy mass collisions could be observed with the help of GW detection. Several cosmic events occurred in the galaxy but only few of them were recorded with observatory proof before GW detections. Several scientific communities from various parts of the world come forward to work in the field of GW detection due to its importance in the future scientific world. Detection of GW has several limitations as discussed but in overcoming such limitations, we get the results of the most anticipated historical events. Our research article briefs the basic elementary cause of GW, propagation of GW, its effect over any objects, limitations while detection, successful/ failure detectors, principle behind the detection, infrastructure with architecture of GW detectors and finally elaborates the various successful detection that has been made in the recent times. Research & Development desk of GW observatories pursue their continuous research in the observatory device optimization phase.

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