A New Tool to Study Universe: Gravitational Waves

Jyoti kapil

Maitreyi college,

University of Delhi

E -mail: jyoti.physics@gmail.com

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Abstract

The most elusive Gravitational waves have finally been detected by the Laser Interferometer Gravitational waves Observatory (LIGO) located in United States, produced by the collision of two massive black holes almost 1.3 billion years ago. The discovery has confirmed the predictions made by Albert Einstein almost a century back in 1916 about the existence of gravitational waves.

Introduction:

11th Feb, 2016 was a remarkable day not just for the scientific community but for the human kind, a day when an international team of scientists, including Indian scientists, announced the first direct detection of the most elusive waves: the gravitational waves. The LIGO (Laser Interferometer Gravitational waves Observatory) observatory in United States heard and recorded the sound of gravitational waves for the first time ever in history which were produced by the collision of two massive black holes 1.3 billion years ago.

The signals of this event were first recorded on 14^{th} Sep, 2015. It was a century back, in 1916, when the world famous physicist, Albert Einstein, first hypothesized the existence of gravitational waves. According to him, the whole Universe is permeated by a flexible space-time fabric and the sheer presence of matter or energy results in warping or curving of the space-time around it which gives rise to gravity and whenever a mass is accelerated on the surface of this fabric, gravitational waves are produced.

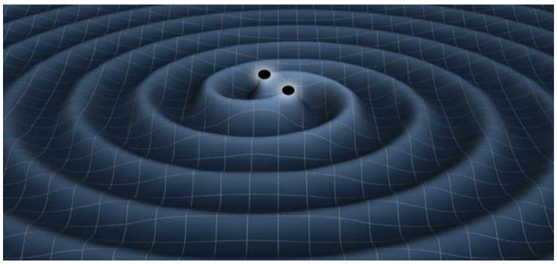

FIG. 1The binary system of black holes orbiting each other and producing gravitational waves; source: www.space.com

WHAT ARE GRAVITATIONAL WAVES?

But exactly what are gravitational waves and how are they produced? According to Einstein, the three dimensions of space and one dimension of time are unified in a single 4 dimensional space-time. This unified space-time fabric is warped by the presence of heavy objects like planets and stars, akin to the curvature produced in the surface of a rubber sheet or a trampoline by a marble or a heavy iron ball. Due to this depression produced in the space-time fabric a nearby object experiences an attractive force towards it which we know as “gravity”, similar to a marble rolling down on the surface of the trampoline towards a depression produced by the heavy iron ball. Heavier the object larger is the curvature produced in the space-time fabric and larger is the force of attraction (gravitational pull) experienced by a body in its vicinity.

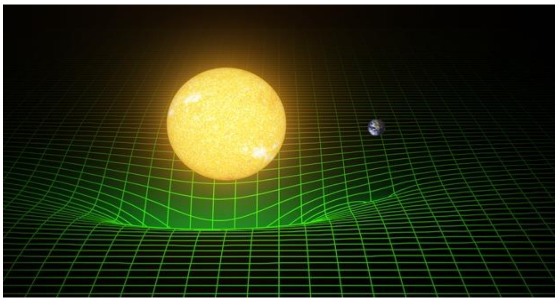

FIG. 2 warping of space-time; source: www.ligo.caitech.edu

This is the reason why earth and other planets move around Sun. Whenever a cataclysmic event happens in the outer space, such as neutron stars or black holes orbiting each other at great speeds, gravitational waves are produced as ripples in the fabric of space-time and travel outward from the source with the speed of light, similar to the ripples produced on the surface of water in a pond when a pebble is dropped in it. In general, anything having mass when accelerated, produces gravitational waves.

Any accelerated mass which we observe around us; a moving car, a rotating top or a planet moving around sun, is a source of gravitational waves, but the strength of these waves is quite weak rendering them very difficult to be detected. Strong gravitational waves are produced by violent or catastrophic events taking place in the outer space such as coalescing neutron stars or white dwarf stars, supernovae, colliding black holes or the Big Bang itself. The gravitational waves which have been detected by the LIGO detector were produced by two massive black holes having masses 36 times and 29 times the mass of the sun, orbiting about each other at tremendous speed, continuously losing their energy and finally colliding and forming a single black hole having mass 62 times the mass of the sun; the remaining mass (3 times the mass of the sun) being radiated as energy in the form of gravitational radiation (energy carried by gravitational waves).

DETECTION:

Was it easy to detect these waves? Certainly not! From the day when the gravitational waves were first predicted by Einstein, scientists and engineers all over the world made efforts to devise some method to detect them directly, but till now they had been able to get only some indirect proof of their existence. Like in 1974 the strong evidence of existence of gravitational was found by Joseph Taylor and Russell Hulse from the radiation emitted by a binary system of stars, one of them was a pulsar, revolving about each other and observing how their orbital period was continuously reducing, losing energy as a result, and giving off this lost energy as gravitational waves. But the idea of making use of a laser interferometer for direct detection of gravitational waves had already been taken up by then, the fundamental principle employed by LIGO. LIGO is an observatory having world's most sensitive experimental setup for detection of gravitational waves. It is so sensitive that it can detect vibrations from its nearby regions to as far as deep regions of the outer space.

FIG.3 LIGO at Livingston and Hanford; Source: www.ligo.caltech.edu

It is not a single observatory; there are two observatories working in unison, one located at Hanford, Washington and the other 3002 k.m. away from it, at Livingston, Louisiana. The reason for the "twin observatory" and their being so far apart is to make the observations of gravitational waves more prominent over any local noise by filtering out the noise detected by the detectors due to a number of sources like vehicles moving nearby, any internal fluctuations in the laboratory or instruments, earthquakes etc.

DESCRIPTION OF THE EQUIPMENT:

The heart of this experimental setup is a large "laser interferometer" which works on the principle of "interference of waves". It is the largest interferometer in the world consisting of two 4k.m. long steel vacuum tubes, 1.2m in diameter arranged perpendicular to each other, and having mirrors at their ends to reflect light. It consists of a beam splitter which splits the laser beam coming from a laser source into two beams of equal intensity, travelling down the two arms of the interferometer. To make the effective distance travelled by the laser beam larger in an arm, two more mirrors are arranged near the beam splitter, one in each arm. This is done to increase the sensitivity of interferometer because larger the distance travelled by the beam before interference, more sensitive it becomes to vibrations. The laser beam travelling down the arm suffers multiple reflections between the end mirror and the mirror near the beam splitter, making the effective distance travelled by the beam much larger than the physical distance of 4k.m. before superimposing with the laser beam coming from the other arm.

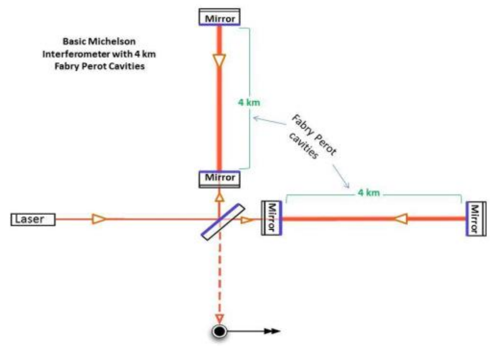

FIG. 4 The Interferometer (modified version of a basic Michelson's Interferometer) used in LIGO; source: www.ligo.caltech.edu

The advanced LIGO can detect change in its arm's length to 10,000 times smaller than the diameter of a proton, making it most sensitive instrument till date. In the absence of any gravitational waves, the beams reaching the detector superimpose on each other destructively producing no resultant light. But in the presence of gravitational waves, the arm length of the interferometer change; if one arm stretches, the other is contracted and vice-versa because the space-time is distorted by the gravitational waves. Because of this contraction and expansion of the arms, one laser beam travels larger distance as compared to the other at a given time. As a result the two beams do not interfere destructively and some light is detected by the detector, which carries information about the incoming gravitational waves.

SIGNIFICANCE OF THE DISCOVERY:

Why is the scientific community so excited and thrilled about this discovery? Why is it so significant? The answer is simple- the detection of gravitational waves has given us a new vision to look and explore the universe from a completely new perspective, revealing the secrets of the deepest region of space. The information carried by gravitational waves is different from that carried by light waves, x-rays, gamma rays etc.; they can pass through matter unchanged unlike electromagnetic waves which get absorbed or reflected when interact with matter. This will make us understand events in the outer space which do not radiate in electromagnetic spectrum and therefore go unnoticed. With the help of these waves we would be able to track supernovae, understand life cycles of black holes and neutron stars. It would also make it possible to get more information about dark matter and the Big Bang itself. The discovery has also provided an evidence for the existence of black holes. The contribution of Indian scientists has also been significant in this discovery. And it can be said that they have been well rewarded by the Indian government by approving the construction of a LIGO observatory in India; definitely beginning of a new era for science and humanity.

REFERENCES:

[1] Concepts of Modern Physics, 6th Edition, by Arthur Beiser

[2] https://www.ligo.caltech.edu

[3] https://www.google.co.in