Phenomenon of Gravitational Waves Reaching the Earth Surface due to Black holes in Space

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Abstract: The first direct detection of gravitational waves and the first observation of the collision and merger of a pair of black holes are detected recently a week back. The collision of black holes has led to emission of gravitational waves, gives us the confirmation to prediction given by Einstein a century ago[3] Thus, the analysis of gravitational waveforms allows us to learn about their source and, if there are more than two detectors involved in observation, to estimate the distance and position of their source on the sky. This paper is to bring to light the technology evolved in engineering for the study of astrophysics.

Keywords: Gravitational waves, black holes, binary neutron stars, ligo, Quadrupole moment, Esa, astrophysics.

INTRODUCTION

Gravitational waves are ripple in the curvature of space-time, produced by some of the most violent events in the cosmos such as the collisions and mergers of massive compact stars. Their existence was predicted by Einstein in 1916 when he showed that accelerating massive objects would shake space-time so much that waves of distorted space would radiate from the source. These ripples travel at the speed of light through the universe, carrying information about their cataclysmic origins as well as invaluable clues to the nature of gravity itself. Gravitational waves propagate as waves which are travelling outward from the source. Curvature are created by mass, more mass more is the curvature of space-time[1]. Gravitational waves transport energy as gravitational radiation. This was given on the basis of general relativity. Gravitational wave is seen only at finite speed. The existence of these gravitational waves is possible consequence of the Lorentz invariance of general relativity which brings the concept of a limiting speed. In certain circumstances, accelerating objects generate changes in this curvature which propagates outwards at the speed of light in a wave like manner. These propagating phenomena are known as Gravitational waves.

SOURCE

Binary neutron stars are predicted to be a powerful source of Gravitational waves. These waves coalesce due to large acceleration of their masses as they orbit close to each other. The effect on earth is predicted to be very small, having strains of less than 1 in 10^{20}. To demonstrate the existence of these waves' scientists developed detectors which are even more sensitive than the gravitational wave.

"Gravitational wave should penetrate regions of space that electromagnetic waves cannot." This provides observer on earth the information about black hole and other objects in the universe. There are different frequency bands to detect Gravitational waves which would be plausibly detected from 10^7Hz to 10^{11}Hz. experimentally; particles change their state of manner when Gravitational waves pass through it. In this Amplitude is constant, Plane of polarization changes. Here, amplitude refers to the size of the wave. Speed, wavelength and frequency of a Gravitational waves are related by the equation $c=\lambda f$, same as the equation for a light wave. Gravitational waves are radiated by objects in which motion involves acceleration provided that the motion is not perfectly symmetric. A motion of two massive stars like Neutron stars or Black holes (perfectly round objects made of pure empty, warped space-time, predicted by general relativity) orbiting each other at higher speeds then significant amount of Gravitational radiations would be given off.

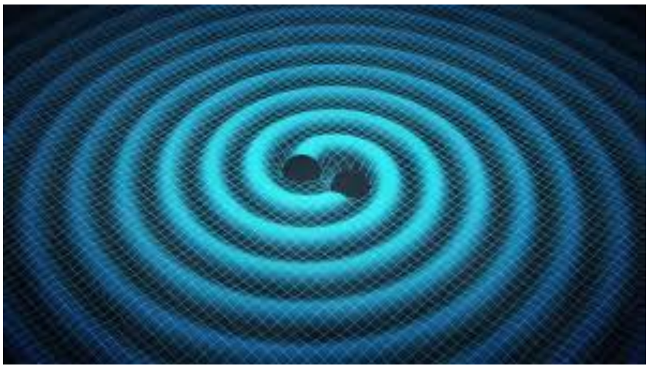

Fig 1 emission of gravitational waves

CONCEPT

Gravitational waves takes energy away from the source and in the case of bodies which are orbiting, this is associated with a decrease in orbit. For example a simple system of two masses like earth-sun system which is moving very slowly when compared to the speed of light in circular orbits. Assuming these two masses revolve around each other in a circular orbit in X-Y plane. The masses follow simple Keplerian orbits and such orbits represents quadrupole moment. Let M1 and M2 be the masses and they are separated by a distance R. The power radiated by this system is given by the equation

$$P== -32/5\ G^4/C^5\ (M1M2)^2\ (M1+M2)/R^5$$ [7]

Where G=Gravitational constant, c=speed of light in vacuum, the negative sign indicates that power is driven away by the system. In theory the loss of energy in earth-sun system through gravitational radiation could eventually drop the earth into the sun. However the total energy of the earth orbiting the sun that is kinetic energy + gravitational potential energy is $1.14*10^3$ joules out of which only 200 joules per second is lost through gravitational radiation, leading to decay in the orbit by $1*10^{15}$ meters per day. This is roughly the diameter of a proton. The time taken by earth to spiral onto the sun at this rate would be $1*10^{13}$ times more than the current age of the universe. In case of two bodies orbiting in the same orbit, it first circularizes their orbit and then shrinks their radius, the energy of orbit is reduced, the distance between the bodies' decreases and the bodies rotate more rapidly. The angular momentum is reduced which is carried off by gravitational radiation. When the radius has **shrunk** to half of its initial value, it now shrinks eight times faster than before. As radius decreases, the power loss to gravitational radiation increases even more. A loss of energy from the orbit results in even more rapid and effective decrease in the distance between the two bodies. They will eventually merge to form a black hole and radiate gravitational waves. This is referred to as inspiral which is observed in pulsar signals.

The quadrupole moment of a system is approximately equal to the mass M of the part of the system that moves, times the square of the size R of the system. The third order time derivative of the quadrupole moment is

$$Q = MR^3/T^3 = MV^2/T = E_{NS}/T$$ [4]

V= mean velocity of source's non spherical motion.
E_{NS} = kinetic energy of non-spherical motion
T = timescale for a mass to move from one side of the system to other side.

For a self Gravitating system $T \sim \sqrt{R^3/GM}$.[6]

One of the most important properties of gravitational radiation sources is orbital lifetime**.** It determines the average number of binary stars in the universe that are close enough to be detected. Short life time binaries are few in number but are strong sources of gravitational radiation. Long life time **binaries** are more plentiful in number but are weak source of gravitational radiation. Gravitational waves propagate through matter with little interaction. These are hard to detect, but carry uncontaminated information about their sources[6]. Simplest Gravitational waves are those with constant frequency. Gravitational waves have important and unique properties such as; firstly there is no need of any of matter to be present nearby for the waves to be generated by a binary system which has uncharged black holes, which would emit no electromagnetic radiation. Secondly, gravitational waves can pass through any intervening matter without being scattered. These two features the gravitational radiation to carry information about astronomical phenomena**.**

HISTORY

In 1915 Albert Einstein published the theory of general relativity[7]. A year later in 1916 Einstein predicts that Gravitational wave exist as a consequence of the theory of general relativity. Richard Feynman in the year 1957 predicts that gravitational wave exist and are theoretically detectable. There was an indirect conformation of existence of gravitational waves in the late 1970s. In 1984 Kip Thorne and Ronald Drever found LIGO. Astronomers at the Harvard-Smithsonian Centre for astrophysics claim that they have detected and produced "the first direct image of gravitational waves across the primordial sky" within the cosmic microwave background. On 19 June 2014, a lowered confidence in conforming the cosmic inflation findings is reported. There was a further reduction in confidence on 19 September 2014 and even more less confidence on 30 January 2015. "Dark energy may distort gravitational waves", stated by astrophysicists at Penn University cites this circumstance as a reason for lack of direct detection. On 11 February 2016, the advanced LIGO team announced that they detected gravitational waves on September 14, 2015 from a merger of two black holes about 400 megapersec (1.3 billion light years) from earth[4]. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational –wave strain of $1*10^{-21}$[10]. The two black holes were 36 and 29 solar masses, which merged into a spinning 62solar mass black hole. The **LIGO** named this merger as GW 150914[8].

DETECTION

A device theorized to detect the expected wave motion is called Weber bar. This is a large solid bar made of metal, isolated from outside vibrations. Strains in space due to an incident gravitational wave excite the bar's resonant frequency and thus be amplified to detectable levels.

Fig.2 HANDFORD WASHINGTON

Gravitational waves are not easily detectable. When gravitational wave reaches the earth, they have small amplitude which requires extremely sensitive detectors, and other source of sound can overwhelm the signal. To overcome this, advanced and highly sensitive detectors are used. LIGO (laser interferometer gravitational wave observatory) has three detectors one in LIVINGSTON, LOUISIAN, one at the HANDFORD side in RICHLAND, WASHINGTON and a third which is formerly installed at HANDFORD is planned to shift to INDIA[11]. LIGO is one of the largest gravitational wave observatory it uses the physical properties of light and space itself to detect gravitational waves. After undergoing major updates in the year 2015 the LIGO detectors began operations as advanced LIGO, the first of significantly more sensitive global network of advanced detectors. An interferometer like LIGO consists of two arms each of four km long placed at right angles to each other, along which a laser beam is placed and reflected by mirrors at each end[9]. Suspended mirrors play the role of "test particle", placed in perpendicular direction. When gravitational wave passes by the stretching and squashing of space causes the arms of the interferometer to lengthen and shrink alternatively. One arm gets longer while the other arm gets shorter and vice versa. As there is a change in the lengths of the arms of the interferometer, the laser beams takes different time to travel through the arms which means that the two beams are no longer "in step" and thus an interference pattern is produced. This is why we refer to the LIGO detectors as "Interferometer". The light is reflected on the mirrors and returns back to the beam splitter and then to a photo detector where the fringe pattern is monitored. The difference between the two arm lengths is proportional to the strength of passing Gravitational wave strain and this number is very small. For a Gravitational wave the strain is expected to be around 1/10000th the width of proton. Laser through long tunnels try to sense ripples in the fabric of space-time. Time gap in which they measured these waves was 7 milliseconds. The signal sweeps upwards in frequency 35 to 250Hz with a peak Gravitational wave strain of $1*10^{-21}$. It matches the wave predicted by general relativity for the inspiral and merger of a pair of black hole and the ring down of the resulting single black hole. LIGO estimated that the peak Gravitational wave power radiated during the final moments of the black hole merger was more than ten times greater than the combined light power from all the stars and galaxies in the observable universe[11]. Strong Gravitational waves are generated by bulk (coherent) motion. They require strong velocity (compact object like black holes and neutron stars).

Fig.3 LIVINGSTON

Space based interferometers, such as LISA and DECIGO are also being developed. LISA'S design called for three test masses forming an equilateral triangle, with lasers from each spacecraft to other spacecraft which forms two independent interferometers. The setup is in vacuum far away from the earth and noise. A mission on LISA is to be taken by EUROPEAN SPACE AGENCY, UK around 2020.

CONCLUSION

The remarkable achievement of the first direct detection of gravitational waves and observation of a merging black hole has taken the area of astrophysics to a next astonishing level[1].The upcoming years will have more and rapid improvements in the advanced LIGO detectors, giving us the more possible and accurate predictions.

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