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AMPLITUDE RANGE OF GRAVITATIONAL WAVES FROM COMPACT BINARY NEUTRON STAR

Bringen, B.[1*i], Bakwa, D. D.[2], and Girma, D. P.[3]
[1]Department of Integrated Science, School of Sciences,
Kashim Ibrahim College of Education, Maiduguri, Nigeria
[2]Department of Physics, Faculty of Natural Sciences, University of Jos, Nigeria
[3]McAulleyMemorial Secondary School, Ballang, Shipang, Pankshin,
Plateau State, Nigeria

Abstract:
This research is concerned with the mysteries of neutron stars and the quest for gravitational waves. Neutron stars are anticipated sources of gravitational waves, and are expected to be detectable within the next decade using kilometre-scale laser interferometry especially the aLIGO. We estimate the range of amplitudes that the waves may have if a neutron star spirals inside a giant star in the end phase of binary evolution. The signal of the calculated values with a peak gravitational-wave strain of h ~ $5.749 \times 10^{-22} - 3.992 \times 10^{-22}$ matches the strain amplitude sensitivity range h ~ 10^{-23} - 10^{-18} of LIGO and VIRGO for the inspiral and merger of a pair binary systems. The results obtained in this research as compared to aLIGO's values of GW detection has proved beyond reasonable doubt that NS are promising candidates; which imply that there are more neutron stars (binary systems) out there than expected.

Keywords: amplitude, gravitational wave, neutron stars, compact binary

Introduction

The Gravitational Waves (GWs) are a prediction of Einstein's General theory of relativity; when Einstein first proposed general relativity in 1916, an initial piece of that theory was the existence of GW (Maggiore, 2013). The GWs are essentially the ripples of space time itself. Einstein did not think of it as a force, but as a curvature of space time, where he thinks of membrane or cushion where in the centre of it put a bouncing ball,

[i] Correspondence: email bbringen@yahoo.com

the cushion curves inwards; if you put a plane marble at the edge, the plane marble falls in towards the bouncing ball, that was Einstein's way thinking of gravity, gravity is geometry. Gravity is not static, GW are essentially radiated by very massive objects, when these objects accelerated and they go out ward from that object and out into the universe (Maggiore, 2008).

If for example, considering some source in the sky, like a pair of Neutron Stars orbiting each other, as they orbit each other, they radiate GW and those GWs are travelling from the source towards the observer at the speed of light (Kostas, 2002). Gravitational waves alternately stretch and squeeze space-time both vertically and horizontally as they propagate. Test particles in the presence of a passing gravitational wave will experience gravitational tidal forces that alternately stretch and squeeze along orthogonal axes in the plane perpendicular to the direction of propagation. The tidal deformations preserve the area enclosed by a ring of test particles, so a measure of the strength is the relative fractional deformation, or dimensionless strain amplitude, $h = 2\Delta L/L$, where L is the length and ΔL is the change in length.

The emission of gravitational radiation dissipates the kinetic or internal energy of the star so that the final product of the evolution is an axisymmetric and/or non-rotating object. Then, each source can be characterized by a decay time, the time during which gravitational waves are emitted (it is determined, for instance, by the spin down rate for rotating neutron stars). Here, we are interested in those sources which radiate in the sensitivity band of laser interferometeric gravitational wave observatory (LIGO): they essentially involve compact objects, namely neutron stars. The number of neutron stars in the Galaxy has been estimated to be of the order of 10^9, with a comparable number of stellar mass black holes (van Paradijs, 1995).

In binary neutron star system in VIRGO cluster, a 1000 times further than the Hulse – Taylor binary so allowing a further 1000 times out; hence, the strain intended to measure goes to 10^{-21}; so the goal of LIGO is to try to measure GW strains at the level of 10^{-21} using kilometre long detector (Asi, 2015). The relative displacement to be measured then corresponds to about 10^{-18}m. The efforts of LIGO is still to measure something at a level a 1000 time smaller than a proton using a sophisticated interferomtric detector such as the Advance LIGO. A laser interferometer is an alternative choice for GW detection, offering a combination of very high sensitivities over a broad frequency band.

This research considers the possibilities that neutron stars may emit radiation at certain amplitude detectable by advance detectors.

Source of Gravitational Waves

Gravitational waves are emitted in many processes involving isolated stars or binary systems. The emission of gravitational radiation determines an evolution of the emitting source (due to the *gravitational radiation reaction*) so that the amplitude and the frequency of the waves change with time.

LIGO has gathered a full year of data at its design sensitivity, monitoring displacements a thousand times smaller than the size of a proton (Kelvin, et al, 2015; www.ligo.org). Reaching this design sensitivity was a great achievement, and was aided by the formation of a large international collaboration of over 500 people from 35 institutions. LIGO's frequency band is $\sim 10 - 2000$Hz, which corresponds to the last few minutes of the inspiral of binary neutron stars or black holes of a few solar masses, visible to LIGO out to ~ 15 mega parsecs (www.ligo.caltech.edu). Astrophysical sources in this band besides compact object (neutron star) inspirals and mergers include spinning neutron stars in our Galaxy, supernovae, stochastic waves from processes in the early Universe (inflation, phase transitions, etc.) and the large discovery space of unexpected sources and effects in the universe. LIGO can observe neutron star binary inspirals out to a distance of ~ 20Mpc $\sim 6 \times 10^{20}$km, which includes the thousands of galaxies in the Virgo cluster. The fact that no events have been seen yet has been used to place upper limits on the event rates. For binary neutron stars, statistical analyses based on the observed number of progenitor binary star systems indicated an event detection rate of between 1/3000 per year to 1/8 per year (Acernese, for LIGO Scientific Collaboration, 2015).

Interferometric Gw Detectors

Interferometers are investigative tools used in many fields of science and engineering. They are called interferometers because they work by merging two or more sources of light to create an interference pattern, which can be measured and analysed; hence "Interfere-ometer". The interference patterns generated by interferometers contain information about the object or phenomenon being studied. They are often used to make very small measurements that are not achievable any other way. This is why they are so powerful for detecting gravitational waves--LIGO's interferometers are designed to measure a distance 1/10,000th the width of a proton (www.ligo.caltech.edu).

The current networks using lasers comprised of detectors in the US, the Laser Interferometric Gravitational wave Observatory (LIGO), the German- UK detector (GE

0600) in Germany, the French – Italian detector (VIRGO) near Pisa, Italy and the Japanese detector KAGRA (www.ligo.caltech.edu).

A laser interferometer is an alternative choice for GW detection, offering a combination of very high sensitivities over a broad frequency band. Suspended mirrors play the role of "test-particles", placed in perpendicular directions. 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 (www.sciencedirect.com.article).

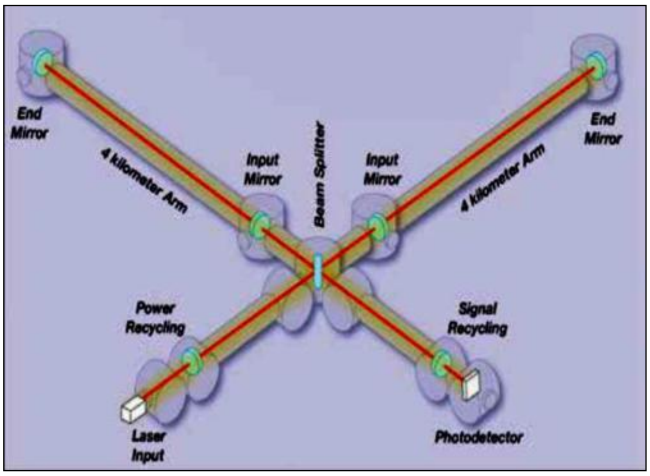

Figure 1: Basic design of the LIGO interferometers

Source: www.ligo.caltech.edu

LIGO consists of two perpendicular, 4-km "arms" as depicted in Figure 1. A laser beam is fired into a beam splitter that sends half the light down one of these arms, and half down the other. The mirrors then reflect the light back the way it came, and the beam splitter combines the two beams back into one, sending the combined beam to a detector. LIGO carefully tunes the lengths of the detector arms so that the light from the arms almost completely cancels out, or undergoes destructive interference, when the reflected beams recombine back at the beam splitter. However, if the arm lengths change slightly due to a passing gravitational wave, then the differences in length will introduce a small difference in phase between the beams from different arms. The waves that would have cancelled each other at the beam splitter will now travel different path lengths and end up producing some light at the detector. It is this interference property of light that is exploited by LIGO to detect gravitational waves (Gregory, 2010). When a gravitational wave passes by, the stretching and compressing of space causes the arms of the interferometer alternately to lengthen and shorten, one getting longer while the other gets shorter, and then vice-versa.

Neutron Star Characteristics

Neutron stars are the most compact objects that can be directly observed. They have a mass of the order of $1 - 2M_\odot$ and a $10 - 20$ km radius, such that the average density equals or exceeds the nuclear matter density of 2×10^{14} g cm^{-3}. In fact, if neutron stars were compressed to just a third of their size, they would be black holes, which can only be detected indirectly. Due to their extreme densities, neutron stars are unique laboratories for particle physics.

A neutron star can be formed through the accretion induced collapse of a white dwarf in a binary system. Also in this case the collapse gives rise to a supernova; depending on the amount of energy released the white dwarf either completely disrupts or transforms into a neutron star (Nomoto & Kondo 1991).

Compact objects-white dwarfs, neutron stars, and black holes are "born" when normal stars "die," that is, when most of their nuclear fuel has been consumed. All three species of compact object differ from normal stars since they do not burn nuclear fuel, they cannot support themselves against gravitational collapse by generating thermal pressure. Instead, white dwarfs are supported by the pressure of degenerate electrons, while neutron stars are supported largely by the pressure of degenerate neutrons. Black holes, on the other hand, are completely collapsed stars-that is, stars that could not find any means to hold back the inward pull of gravity and therefore collapsed to singularities. With the exception of the spontaneously radiating "mini" black holes with masses M less than 10^{15} g and radii smaller than a Fermi, all three compact objects are essentially static over the lifetime of the Universe. They represent the final stage of stellar evolution.

The second characteristic distinguishing compact objects from normal stars is their exceedingly small size (Thorset, & Chakrabarty, 1999). Relative to normal stars of comparable mass, compact objects have much smaller radii and hence, much stronger surface gravitational fields.

Range of Gravitational Wave Amplitude

This research considered the masses of some neutron stars with same radius of 10 Km but different masses and developed a model that could test observation of the amplitude range which these stars (J1518 + 409, B1534 + 12, B1913 + 16, B2127+11C, and B2303 + 46) could possibly be within the detectors sensitive band.

The fundamental geometrical framework of relativistic metric theories of gravity is space-time, mathematically described as a four-dimensional manifold whose points are called events. Every event is labelled by four coordinates $x^{\mu}(□ = 0, 1, 2, 3)$; the three coordinates $x^{i}(i = 1,2,3)$ give the spatial position of the event, while x^{0} is related to the coordinate time $t(x^{0} = ct$, where c is the speed of light). The choice of the coordinate system is quite arbitrary and coordinates transformations of the form $\tilde{x}^{\mu} = f^{\mu}(x^{\lambda})$ are allowed. The motion of a test particle is described by a curve in space-time. The distance ds between two neighbouring events, one with coordinates x^{μ} and the other with coordinates $x^{\mu} + dx^{\mu}$, can be expressed as a function of the coordinates via a symmetric tensor $g_{\mu\nu}(x^{\lambda}) = g_{\nu\mu}(x^{\lambda})$, i.e.,

$$\boldsymbol{ds^{2} = g_{\mu\nu} dx^{\mu} dx^{\nu}} \qquad (1)$$

This is a generalization of the standard measure of distance between two points in Euclidian space. For the Minkowski space-time (the space-time of special relativity),

$$g_{\mu\nu} \equiv \eta_{\mu\nu} = diag(-1,1,1,1) \qquad (2)$$

The symmetric tensor is called the metric tensor or simply the metric of the space-time. The information about the degree of curvature (i.e., the deviation from flatness) of a space-time is encoded in the metric of the space-time. According to general relativity, any distribution of mass bends the space-time fabric and the Riemann tensor $\boldsymbol{R_{\mu\nu}}$ (that is a function of the metric tensor $\boldsymbol{g_{\mu\nu}}$ and of its first and second derivatives) is a measure of the spacetime curvature. The Riemann tensor has 20 independent components. When it vanishes the corresponding space-time is flat. In this thesis, we will consider mass distributions, which we will describe by the stress-energy tensor $\boldsymbol{T_{\mu\nu}(x^{\lambda})}$.

Einstein's gravitational field equations connect the curvature tensor (see 3) and the stress-energy tensor through the fundamental relation:

$$\boldsymbol{G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = kT_{\mu\nu}} \qquad (3)$$

This means that the gravitational field, which is directly connected to the geometry of space-time, is related to the distribution of matter and radiation in the universe. $\boldsymbol{R_{\mu\nu}}$ is the Ricci tensor and comes from a contraction of the Riemann tensor, $\boldsymbol{R}$ is the scalar curvature, while $\boldsymbol{G_{\mu\nu}}$ is the Einstein tensor, $\boldsymbol{k = 8\pi G/c^{4}}$ is the coupling constant of the theory and is the gravitational constant. The vanishing of the Ricci tensor corresponds to a space-time free of any matter distribution. However, this does not imply that the Riemann tensor is zero. As a consequence, in the empty space far from any matter distribution, the Ricci tensor will vanish while the Riemann tensor can be nonzero; this means that the effects of a propagating gravitational wave in an empty space-time will be described via the Riemann tensor.

The equations of structure are obtained using gravitational waves in the theory of linearized gravity. Within this structure, it is assumed that space-time, described by the metric tensor, is approximately flat. In other words, it is decomposed into the flat Minkowski metric $\eta_{\mu\nu}$ and some contribution $h_{\mu\nu}$

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \tag{4}$$

Since the space-time is approximately flat, this contribution must be small. As a result, in calculating physically significant quantities only terms up to linear order in $h_{\mu\nu}$will be kept

$$||h\text{?}v|| << 1 \tag{5}$$

Equation 2 is not a simple expression to work with; it would be suitable to reduce the Einstein equation. One way of doing this is to cease working with $\mathbf{h}_{\mu\nu}$ and instead work with an expression that is known as the trace-reversed metric which is defined as

$$\bar{h}_{\mu\nu} = h_{\mu\nu} - \frac{1}{2} g_{\mu\nu} h \tag{6}$$

and its name stems from the fact that its trace is the opposite of the original metric. Choosing the trace-reverse of $h_{\mu\nu}$ and the Lorentz condition,

$$\delta^{\mu} \bar{h}_{\mu\nu} = 0 \tag{7}$$

We find the linearized Einstein Field Equation and can be written elegantly as

$$\Box \bar{h}_{\mu\nu} = -2kT_{\mu\nu} \tag{8}$$

Where

$\Box = \delta^{\mu}\delta_{\mu}$ is the flat-space d'Alambertian, and

$k = 8\pi G/c^4$

Therefore,

$$\Box \bar{h}_{\mu\nu} = -\, 16\pi G T_{\mu\nu}/c^4 \tag{9}$$

In order to study the propagation of gravitational waves and their interaction with test masses, we are interested in the governing equations outside the source, i.e.$\boldsymbol{T_{\mu\nu}} = \mathbf{0}$:

$$\Box \bar{\boldsymbol{h}}_{\mu\nu} = 0 \tag{10}$$

In the vacuum case, the Lorenz gauge condition alone is not enough to fix the gauge freedom. Further inspection shows that the Lorenz gauge condition is not violated by imposing $\bar{\boldsymbol{h}} = 0$, then $\bar{\boldsymbol{h}}_{\mu\nu} \equiv \boldsymbol{h}_{\mu\nu}$, and $\boldsymbol{h}^{0i} = \mathbf{0}$. The Lorenz condition then becomes:

$$\boldsymbol{\partial^0 h_{00} = 0} \tag{11}$$

$$\boldsymbol{\partial^i h_{ij} = 0} \tag{12}$$

This means that $\boldsymbol{h_{00}}$ corresponds to the static (time-independent) part of the gravitational field; the time-varying gravitational degrees of freedom, the GW itself, is contained in the time-dependent components $\boldsymbol{h^{0i}}$.

By via exploiting the gauge degrees of freedom we have set:

$$\boldsymbol{h^{0\mu} = 0} \tag{13}$$

$$\boldsymbol{h^i{}_i = 0} \tag{14}$$

$$\boldsymbol{\partial^0 h_{ij} = 0} \tag{15}$$

This set of conditions defines the transverse-traceless gauge (TT gauge), the most convenient gauge to express gravitational waves outside the source. The general complex solutions of Equation (10) are plane-wave solutions:

$$\boldsymbol{h_{\mu\nu} = A_{\mu\nu} e^{ik_\sigma x^\sigma}} \tag{16}$$

with $\boldsymbol{k^\mu} = \boldsymbol{\omega}, \boldsymbol{k^i}$ the wave vector. In the TT-gauge this general expression can be rewritten as:

$$\boldsymbol{h_{ij}{}^{TT} = e_{ij} e^{ik_\mu x^\mu}} \tag{17}$$

Where $\boldsymbol{e_{ij}}$ and $\boldsymbol{k_\mu}$ are the polarization tensor and vector respectively.

The Einstein equation (9) can readily be solved with the use of method of Green's functions.

The retarded Green's function is given by

$$G(x-x') = -\frac{1}{4\pi}\frac{1}{|\vec{x}-\vec{x}'|}\delta\left(t-\frac{|\vec{x}-\vec{x}'|}{c}-t'\right) \quad (18)$$

This of course satisfies the defining relation for a Green's function, namely:

$$\Box_x G(x-x') = \delta^{(4)}(x-x') \quad (19)$$

The usefulness of such a function resides in the fact that the general solution to an equation such as (8) can be written as:

$$\bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4}\int d^4x'\, G(x-x')T_{\mu\nu}(x') \quad (20)$$

Substituting (17) into (19) yields

$$h_{\mu\nu} = \frac{4G}{c^4}\int T_{\mu\nu}\frac{x'(x', t-|x-x'|)/c}{|x-x'|}d^3x' \quad (21)$$

Assuming that the GWs are generated by a weak source and observed at large distance from the source, i.e. $r >> R$, where R is the characteristic size of the source. In this case, one can perform the standard multipole expansion of the denominator analogous to the expansion of the electromagnetic field at large distance from the source:

$$\frac{1}{|x-x'|} \approx \frac{1}{r} + \frac{x^i x'^i}{r^3} \quad (22)$$

In the limit $\boldsymbol{r} \Rightarrow \infty$ the asymptotic solution of the linearised field equations therefore is:

$$h_{\mu\nu} = \frac{4G}{rc^4}\int T_{\mu\nu}\, d^3x'(t-r, x') \quad (23)$$

that in linearized theory $\boldsymbol{T_{\mu\nu}}$ fulfills the flat-space conservation law, i.e., $\partial^\mu \bar{h}_{\mu\nu} = 0$ and sources therefore move on geodesics in flat Minkowski space. Applying the conservation law, we find that

$$\int T_{ij}\, d^3x' = \frac{1}{2}\frac{d^2}{dt^2}\int x x^i x^j\, T_{00}\ \ d^3x \quad (24)$$

Assuming a standard stress-energy tensor, the *tt*-component denotes the rest-mass energy density of the source μ(x). We can now define the second moment of mass or moment of inertia tensor:

$$\boldsymbol{I_{ij}} = \int \boldsymbol{d^3 x_\mu(t, x') x_i x_j} \quad (25)$$

Hence, the asymptotic solution describing GWs generated by weak sources is found to be:

$$\boldsymbol{h_{\mu v}} = \frac{2G}{rc^4}\frac{d^2}{dt^2}\boldsymbol{I_{ij}}(t-r) \quad (26)$$

Equation (16) is rather instructive:

i) It shows that GWs are generated by accelerated sources similar to electromagnetism where accelerated charges generate EM radiation,

ii) The radiation obeys a $\frac{1}{r}$-fall-off, which implies that GWs generated by astrophysical sources are indeed weak when they reach ground-based detectors (far from the source), and

iii) Gravitational radiation is of quadrupolar nature as the conservation laws do not permit monopole and dipole gravitational radiation.

If the motion inside the source is highly non-spherical, then a typical component of $\frac{d^2}{dt^2}\boldsymbol{I_{ij}(t-r)}$ will (from Equation (24)) have magnitude $\boldsymbol{Mv^2}_{\boldsymbol{N.S}}$., where$\boldsymbol{V_{N.S}}$ is the non-spherical part of the squared velocity inside the source. So one way of approximating any component of Equation (26) is:

$$\boldsymbol{h_{\mu v}} = \frac{2GMv^2{}_{N.S}}{rc^4} \quad (27)$$

Suppose a neutron star of radius **R** spins with a frequency **f** and has an irregularity, a bump of mass **m** on its otherwise axially symmetric shape. Then the bump will emit gravitational radiation again at frequency **2f** because it spins about its centre of mass, so it actually has mass excesses on two sides of the star, and the non-spherical velocity will be just$\boldsymbol{V_{N.S} = 2\pi Rf}$. The radiation amplitude will be,

$$\boldsymbol{h_{\mu v}} = \frac{2Gm}{rc^2}\left(\frac{2\pi Rf}{c}\right)^2 \quad (28)$$

But,

$$f = \frac{(\frac{Gm}{R^3})^{1/2}}{4\pi} = \sqrt{\frac{Gm}{16\pi^2 R^3}} \quad (29)$$

Substituting (29) into (28) yields,

$$h_{\mu\nu} = \frac{2Gm}{rc^2}\left\{\left(\frac{2\pi R}{c}\right)\left(\frac{Gm}{16\pi^2R^3}\right)^{1/2}\right\}^2$$
$$= \frac{2Gm}{rc^2}\left\{\frac{4\pi^2R^2}{c^2}.\frac{Gm}{16\pi^2R^3}\right\}$$
$$= \frac{2Gm}{rc^2}\left\{\frac{1}{c^2}.\frac{Gm}{4R}\right\}$$
$$= \frac{2Gm}{rc^2}\left(\frac{Gm}{4Rc^2}\right)$$

Which implies that,

$$h = \frac{1}{2}\frac{G^2m^2}{Rrc^4} \quad (30)$$

Let us make some estimates based on this formula (30) using the different masses of neutron stars for gravitational wave emission.
Therefore, **h** may be obtained using the form in (30) thus as:

$$h = \frac{1}{2}\frac{G^2m^2}{Rrc^4}$$

Putting the parameters for neutron star(s), J1518+4904 we have;
m = 1.56M$_\odot$=1.56x2x10^{30}kg = 3.120x10^{30}kg
R = 10km=10x1000m=10000m = 10^{4}m
r = 15Mpc=15x1000000x3.086x10^{16}m = 4.65x10^{23}m
G = 6.673x10^{-11} Nm^2/Kg^{-2}
C = 3x10^8 m/s

$$h = \frac{1}{2}\frac{(6.67\times10^{-11})^2(3.12\times10^{30})^2}{(10^4)(4.65\times10^{23})(3\times10^8)^4}$$
$$= \frac{4.331\times10^{40}}{7.533\times10^{61}}$$

Therefore,

$$h = 5.749\times10^{-22}$$

which is dimensionless. However, the strain amplitude, **h**, for NSs B1534 + 12, B1913 + 16, B2127**+**11C, and B2303 + 46 were equally calculated using the same formula in equation (30) and presented in table (1)

Results

The calculated results of the strain amplitude estimate for neutron stars (J1518 + 409, B1534 + 12, B1913 + 16, B2127 + 11C, and B2303 + 46) are presented in table 1.

Table 1: Strain Amplitude Estimate for Neutron Star

Star (Source)	M(x 10^{30} Kg)	R (m)	r (x 10^{23}m)	h
J1518 + 4904	1.56	10^4	4.650	5.749×10^{-22}
B1534 +12	1.339	10^4	4.650	4.236×10^{-22}
B1913 +16	1.441	10^4	4.650	4.905×10^{-22}
B2127 +11C	1.349	10^4	4.650	3.992×10^{-22}
B2303 +46	1.30	10^4	4.650	4.318×10^{-22}

Discussion

In this research, we have been able to estimate the amplitude for gravitational waves detection where the GW candidate (Neutron star) can be detected within the sensitivity of the ground based detectors set by Advanced LIGO (aLIGO). Gravitational waves can be emitted by many systems, but, to produce detectable signals, the source must consist of extremely massive objects moving at significant fraction of the speed of light. The main source is a binary of two objects; these include compact binaries made up of two closely orbiting staler-mass objects, such as white dwarfs, Newton stars or black holes.
Advanced LIGO's frequency band is ~ 10 -2000 Hz, which corresponds to the last few minutes of the inspiral of binary neutron stars of a few solar masses, visible to aLIGO out to ~ 15 megaparsecs (Mpc). Astrophysical sources in this band besides compact object (neutron star) inspirals and mergers include spinning neutron stars in our Galaxy. aLIGO can observe neutron star binary inspirals out to a distance of ~ 20Mpc ~ 6×10^{20}km, which includes the thousands of galaxies in the Virgo cluster. Hence, the estimated amplitude in table (1) reveals that the amplitude was found to be h, ~ 10^{-22} and such waves generated within these ranges are targets for the ground-based detectors. The sensitivity of ground based detectors is fundamentally limited at low frequencies because they cannot be shielded from time-varying curvature fluctuations due to the environment.

Conclusion

The landmark discovery that was reported by the Advanced Laser Interferometer Gravitational-Wave Observatory (Advanced LIGO) team, confirming months of rumors that have surrounded the group's analysis of its first round of data has been actualized. Astrophysicists say the detection of gravitational waves opens up a new window on the universe, revealing faraway events that can't be seen by optical telescopes, but whose faint tremors can be felt, even heard, across the cosmos.

The detection ushers in a new era of gravitational-wave astronomy that is expected to deliver a better understanding of the formation, population and galactic role of Neutron Stars and black holes; super-dense balls of mass that curve space-time so steeply that even light cannot escape. When these stars spiral toward each other and merge, they emit a "chirp": space-time ripples that grow higher in pitch and amplitude before abruptly ending. The chirps that LIGO can detect happen to fall in the audible range, although they are far too quiet to be heard by the unaided ear. Physicists are already surprised by the number and strength of the signals detected so far, hence, the results obtained in this research as compared to LIGO's values of GW detection has proved beyond reasonable doubt that NS are positive candidates; which imply that there are more neutron stars and black holes out there than expected. Compact binaries, binary star systems in which each member is a neutron star or black hole are currently the best understood sources of GWs.

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