A Model of Gravitational Waves Based on a Modified Yukawa Potential

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Abstract: A model of gravitational waves is proposed using a complex Yukawa potential which is non-singular and predicts a dual-wave structure composed of incoming and outgoing waves. Using this potential, a fundamental gravitational wave frequency associated with the mass of the Universe is calculated to be the equal to Hubble's Constant. The characteristic out wave frequency of the Earth is calculated to be $3.38\ x\ 10^{-5}$ Hz, which is in good agreement with the range of frequency of gravitation waves as predicted by Hawking and Israel. Also, the Lorentz transformation of the outgoing wave speed to the incoming wave speed predicts the same time dilation as the G44 solution from the Einstein field equations.
Keywords: LIGO, gravitational waves, Yukawa potential

I. Introduction

The recent discovery of gravitational waves by LIGO has provided valuable confirmation of many predictions around gravitational waves. In particular, Hawking and Israel predicted gravitational waves would be observed in the frequency bands of 10^{-8} Hz to 10^{11} Hz [1]. The Laser Interferometer Space Antenna (eLISA) is a unique position to detect the lower end of this band at around 10^{-5} Hz, where it should be able to measure the signal of gravitational waves from the static potential due to the Earth and Moon. The European Pulsar Timing Array (EPTA) has high sensitivity in the 10^{-8} Hz range where it should be able to measure the static gravitational waves from the Sun. The following derivations of a non-singular Yukawa potential describes continuous gravitational waves that result from this static potential. The intermodulation of these continuous wave static wave sources, along with their associated motion, produces the modulated waves which are currently measured by LIGO and which will be measured in the future by eLISA and EPTA.

II. A Complex Yukawa Potential

The standard, non-singular Yukawa potential is modeled by the following equation [2]:

$$V(r) = (A^2)\frac{e^{-kr}}{r} \tag{1}$$

Where A is the amplitude of the potential, k is a coupling constant associated with the particular force involved (in this case a gravitational constant that covers both the far field case of G and near field case of quantum gravity) and r is the range over which the potential acts, in this case the range is assumed to be from 0 to a limited distance encompassed within the Hubble sphere. We modify (1) to become a complex exponential :

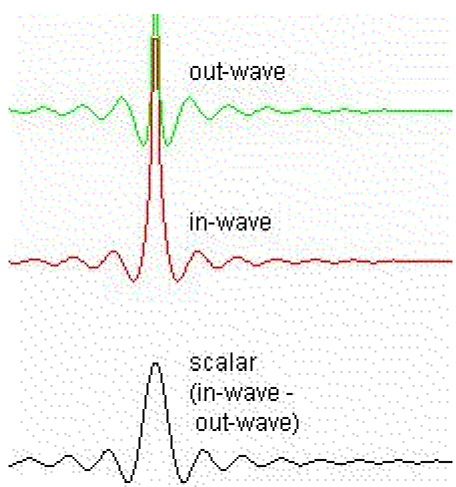
$$V(r) = (A^2)\frac{e^{-kr}e^{i(\omega t + \emptyset)}}{r} \tag{2}$$

Where ω is the wave frequency and $\emptyset$ is the corresponding phase shift of the wave. In an environment where several of the waves in (2) travel towards a single point from all directions, with some asymmetry due to the slight variation of the mass density of local space, we theorize a situation where the incoming waves meet at single point but also experience rotational asymmetry at a high-level. This would result in waves coming back in the same direction they originally came from, producing an interference pattern based on the changes in ω and $\emptyset$. With two potentials of this type oscillating in free space but moving in opposite directions with possibly a different frequency and different phase shifts, we arrive at the final potential:

$$V(r) = (A^2)\frac{e^{-kr}(e^{i(\omega_1 t\,+\,\emptyset_1)} - e^{i(\omega_2 t\,+\,\emptyset_2)})}{r} \tag{3}$$

III. Properties of Interacting Yukawa Potentials

Figure 1 shows a graph of some possible interactions of standing wave potentials shows that the typical singularity of a particle potential (an electron in this case) associated with $1/r$ is replaced with a limiting value of A as r approaches zero due to the Yukawa potential. Figure 2 shows a similar situation where the wave potential has a negative amplitude (relative to the positive amplitude in Figure 1), resulting in the equivalent of a positron.



<u>Figure 1. Interaction Between Potentials Moving in Opposite Directions – Electron</u>

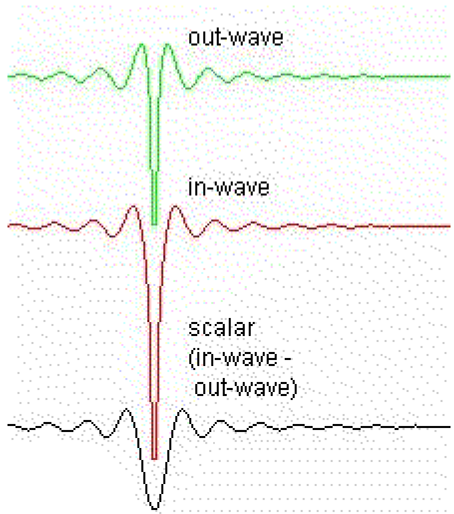


Figure 2. Interaction Between Potentials Moving in Opposite Directions with phase change – Positron

As discussed previously, in an environment where several of the waves in (2) travel towards a single point from all directions, there is the possibility of an asymmetry due to the slight variation of the mass density of local space, where the interacting wave center can experience rotational asymmetry (left-handed or right-handed rotation) which can be interpreted as spin of the particle. There is also the possibility of a phase shift between two wave centers which can correlate with the nature of charge (space tension due to wave centers that are out of phase). In the examples of Figure 1 and Figure 2, this would correspond to the wave centers between the electron and positron being out of phase by 180 degrees. Extensive characteristics of the spin and rotation associated with these interacting wave potentials has been evaluated previously by Wolf [3].

As the Yukawa potential in (2) has no dependency on the other spherical coordinates of ϕ or φ, the resulting scalar potentials of (2) and (3) can be interpreted as results of a scalar force equation of the form:

$$F(t) = m\ddot{r} + b\dot{r} + kr \tag{4}$$

Where m is considered a moving mass, b is considered the equivalent of a frictional coefficient, k is an elasticity constant of the corresponding wave medium and r is the range of interaction. If we identify particles of a standing wave nature as being permanent entities which is the equivalent of b = 0, then for those transient particles that decay we infer that b is a non-zero value which controls the decay constant of $b/\ m$. Also, the frequency of the standing wave is controlled by the ratio of elasticity constant to the mass $(k/\ m)$ with the frequency being determined from:

$$\omega = \sqrt{\frac{k}{m}} \tag{5}$$

The rotational effects of the wave center also changes the speed of the out-going waves based on distance r from the wave center:

$$v = \omega r \tag{6}$$

IV. Gravitational Effects of Multiple Wave Centers

To determine k for gravitational effects, we look at the results of potential energy equivalence to moving mass density,

$$\frac{1}{2}kr^2 = \frac{1}{2}mv^2 \tag{7}$$

From a previous determination of the wave velocity *v* as the speed of light and knowing there are two interacting waves [4] we arrive at,

$$\frac{1}{2}kr^2 = mc^2 \tag{8}$$

We can determine *k* from (8) for gravitational effects for approximate values of the mass of the universe (m = 5.4 x 10^{52} Kg) and its radius (r = 1.9 x 10^{26} meters) [5],

$$k = \frac{2mc^2}{r^2} = 2.7 \text{ x } 10^{17} \text{ Newtons/meter} \tag{9}$$

Then for waves that are traveling across the Hubble radius of the universe, ω in (5) for the mass of the Universe becomes,

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{2.7 \text{ x } 10^{17}}{5.4 \text{ x } 10^{52}}} = 2.23\ x\ 10^{-18}\,\frac{radians}{sec} = Hubble's\ Constant$$

(10)

The results of (10) shows that the fundamental node of standing wave frequencies in this universal model is the Hubble frequency, which is the in-coming wave for all matter in the Universe. Using this model, the cosmological redshift can be explained by understanding the energy transfer through incoming waves and how we view that energy as a function of distance, removing the need for a Doppler shift due to universal expansion [6].

To determine the out-going wave frequency of an object, we need to consider the local mass density around that object. The in-coming waves converge on a local mass density and are rotated and reflected back at a frequency based on local mass density. The results of (7) – (10) can be applied at individual wave level but are demonstrated here by aggregating wave affects to a macroscopic level, with many wave centers combining to produce the gravitational effects that we measure.

For the mass of the Earth, M_E = 5.972 x 10^{24} Kg we find the characteristic ω as,

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{2.7 \text{ x } 10^{17}}{5.97 \text{ x } 10^{24}}} = 2.13\ x\ 10^{-4}\,\frac{radians}{sec} = 3.38\ x\ 10^{-5}\ Hz$$

(11)

For the mass of the Sun, M_S = 2.0 x 10^{30} Kg we find the characteristic ω as,

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{2.7 \text{ x } 10^{17}}{2.0 \text{ x } 10^{30}}} = 3.67\ x\ 10^{-7}\,\frac{radians}{sec} = 5.85\ x\ 10^{-8}\ Hz$$

(12)

For the mass of the Moon, M_M = 7.34 x 10^{22} Kg we find the characteristic ω as,

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{2.7 \text{ x } 10^{17}}{7.34 \text{ x } 10^{22}}} = 1.92\ x\ 10^{-3}\ \frac{radians}{sec} = 3.05\ x\ 10^{-4}\ Hz$$

(13)

As the wave energy falls off as *1/r* and the amplitude-squared (A^2) of the wave is proportional to the rest-energy of the object, we can expect similar results of gravitational influence by applying the traditional gravitational potential of *GM/r* to determine the effect from a given distance.

It is interesting to note that (6) shows the out wave speed from a mass is proportional to frequency and distance ($v = \omega r$). From a given out-wave speed we can also determine a time dilation relative to the in-wave speed (which is the speed of light for most cases) through the Lorentz transformation of the out-wave velocities relative to the in-wave velocities:

$$T = \frac{T_0}{\sqrt{1 - \frac{(\omega r)^2}{c^2}}} = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

(14)

If we use the Earth as an example, $\omega = 2.13\ x\ 10^{-4}$ and at distance from the center of the Earth of *r* = 26,000 km (GPS orbit) we find that the time dilation from (14) is:

$$T = \frac{T_0}{\sqrt{1 - \frac{(2.13\ x\ 10^{-4}\ \ x\ 26\ x\ 10^{6})^2}{c^2}}} = 1.0000000001703 = \mathbf{170.3}\ \boldsymbol{psec\ change}$$

(15)

Performing the same calculation with General Relativity G44 solution (assuming a non-rotating sphere) gives the same result:

$$T = \frac{T_0}{\sqrt{1 - \frac{2GM}{rc^2}}} = \frac{T_0}{\sqrt{1 - \frac{2 * (6.67\ x10^{-11})(5.97\ x10^{24})}{(26\ x\ 10^{6})c^2}}} = \ 1.0000000001703$$
$$= \mathbf{170.3}\ \boldsymbol{psec\ change}$$

V. Measurement and Potential Applications

The platforms currently in use or in development that has the potential to directly measure static gravitational waves or the result of up-modulation between two static wave sources (such as in binary black-hole mergers) (Figure 3).

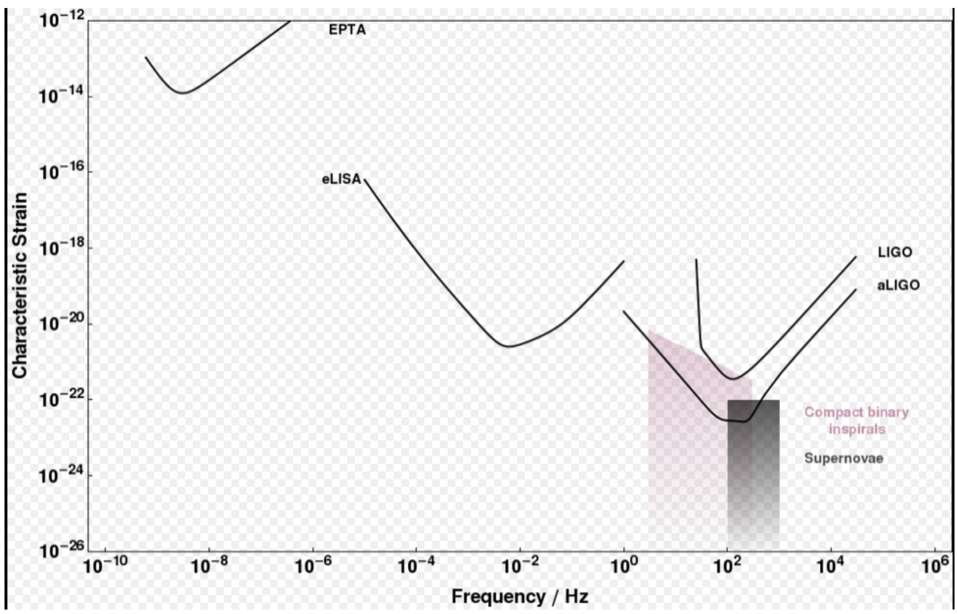


Figure 3. Gravity Wave Detectors in Use or Planned for Future Use

From Figure 3, it is most likely going to be the Evolved Laser Interferometer Space Antenna (eLISA) which sees the monthly variation in the static gravitational wave source between the Earth and Moon (both out wave frequencies fall within the 10^{-5} Hz to 10^{-3} Hz range) when it is fully implemented [7]. The low-frequency static waves from the Earth and Moon are likely to present as a low-noise background with an orbital variation based on the satellite position with respect to the Earth-Moon orbit. The static out wave signal of $9.54x\ 10^{-8}\ Hz$ from the Sun would be measurable with the orbital variation of the European Pulsar Timing Array (EPTA).

Another implication of the presences of these continuous static waves from a mass is the possibility of creating an artificial signal that will destructively interfere with these waves. In the case of the out waves from the Earth, the task is one of generating a signal of frequency $3.38\ x\ 10^{-5}\ Hz$ and a continuously changing wavelength based on the radius *r* from the center of the Earth. This could be accomplished with a vacuum-sealed, high-voltage grid which accelerates electrons or protons to a speed in which their associated out-waves will be of the correct wavelength to cancel the out waves from the Earth for at least part of the out wave cycle. Previous evidence exists from similar experiments such as the Biefield-Brown effect where Thomas Brown demonstrates the results of a positive thrust of two highly-charged, parallel plates in a vacuum [8].

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