

# Light Induced Gravity Phonons

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## Abstract

Einstein theorized that a mass travels towards another mass, not because it is attracted by a force acting across a distance, but because it travels through space and time that is warped by masses and energy. Einstein postulated that this space-time fabric can have wave-like modes which have been measured by the LIGO experiment. A consistent model of the generation of space-time-fabric-modes by a light Photon is derived for slight space-time deformations. Each Photon generates a shower of very small amplitude space-time fabric modes. Each mode can have a number of energy quanta. The probability of a Photon generating a shower of space-time modes is much larger than the probability of all the space-time modes collecting and generating a Photon. Therefore, this process has a **unique Arrow of Time**. Similar to the energy quanta of displacement modes in an elastic medium which is called Phonons, the energy quanta of the space-time fabric modes are called gravity Phonons. Both are tensor waves. Gravity Phonons have spin angular momentum of 2 and propagate with the speed of light. At every step of these calculations, equations derived from the General Relativity Theory by scientists and verified by Astronomical observations or experiments are employed.

## Keywords

Photons, Phonons, Gravity, General Relativity, Space-Time, Generation Rate, Arrow of Time

## Note

In the whole paper numbers such {8} in curly brackets denote equation numbers in the literature.

## 1. Introduction

Einstein [1] theorized in 1916 that a test mass travels towards a mass not because it is attracted by a force that acts across a distance between masses, but because

the test mass travels through space and time that is warped by mass and energy. **In this paper, the Interaction of a light Photon with a space-time fabric that has been deformed by a non-rotating Earth-like mass is described. The derivation is only for a slightly curved space-time fabric.**

A light Photon will not interact to first order with flat space-time, the ordinary four-dimensional Minkowski space. The Earth-like mass is used to remove this symmetry and facilitate the interaction of the Photon with warped space-time.

Einstein also postulated the existence of wave modes in the space-time fabric. This has been verified by the **Laser Interferometer Gravity-Wave Observatory LIGO** experiment [2]. The interaction of a Photon with warped space-time fabric generates space-time modes, which can have any number of energy quanta, called gravity Phonons. The energy quanta of displacement modes in an elastic medium are called Phonons. Because of the similarity of the interaction of light and Phonons, to the interaction of light and the space-time modes, the space-time mode energy quanta are called **gravity Phonons**. The gravity Phonons valid for slight deformation of the space-time fabric only, are different from Gravitons which presumably are valid for all values of gravity. In this paper, the gravity Phonons have an energy of 0.59893 atto eV and a wavelength of 1.7298 Å. These small values are expected since the derivation is based on astronomical observations and experiments.

**In this paper, equations derived from the General Relativity Theory (GRT) and verified by astronomical observations or experiments are employed at every step of the calculations.**

Professor Paul Sutter of Ohio State University and Chief Scientist of the COSI Science Center [3] asks “Why Can’t Quantum Mechanics Explain Gravity?” Quantized models exist for the other three forces, the Electromagnetic Force, the Weak Nuclear Force, and the Strong Nuclear Force. In this paper, a quantized formulation of Einstein’s [1] space-time fabric modes is presented for slightly curved space-time fabric. Thus, now there exists quantized models for **all four forces**, a Gravity Force for slightly curved space-time fabric only, the Electromagnetic Force, the Weak Nuclear Force and the Strong Nuclear Force of the standard model of Physics.

This discussion involves **space-time** which permeates all space at all times, a **light electromagnetic wave**, and a large non-rotating **mass**. The mass used has the same value as the mass of the Earth. The derivation is in four steps:

**FIRST**, to model the affect of the slightly warped space-time on an electromagnetic wave, Einstein’s description [1] of the deflection of a light wave by the curvature of space-time due to a mass is used. This has been verified by observing the deflection of a light beam passing close to the Sun by F. W. Dyson *et al.* [4].

**SECOND**, the affect of the energy of the light wave on the curvature of space-time is described by Einstein’s equation [5]. In Einstein’s equation, the Einstein tensor describes the curvature of space-time, and the affect of the energy of the light wave is described by the electromagnetic stress tensor [5] [6]. The affect of the energy of the light wave on the curvature of space-time is predicted

by the GRT. The GRT has been proven correct in all its tests. Therefore, the affect of the energy of the light wave on the curvature of space-time, predicted by the GRT, must also be correct.

**THIRD**, a Taylor series expansion to second order of the time dilation equation is used for the derivation of the frequency  $\omega$  of the light wave in the presence of gravity as a function of the frequency  $\omega_E$  of the light wave in the absence of gravity and the space-time mode frequency  $\omega_G$ . The gravitational blue shift of the frequency, in this case, of gamma rays emitted by iron  $^{57}\text{Fe}$  samples mounted a vertical elevation of 22.5 m apart has been measured by R. V. Pond and J. L. Sinder [7].

In the **FOURTH** step, Quantum Electrodynamics [8] is used to formulate a Hamiltonian from the above described frequency relationship in second quantized form.

A momentum vector diagram illustrating the affect of the curvature of space-time on a light wave, and the affect of the energy of the light wave on the curvature of the space-time fabric to within a constant for slightly curved space-time fabric only, as shown in **Figure 2** is derived. The values of the change of the light wave momentum and momentum of the light wave generated space-time fabric modes are functions of the deflection angle of the light wave.

This derivation is not valid in the vicinity of large masses such as Black Holes and Neutron Stars. It is also not applicable to the Early Universe, where the mass density was much larger than it is now, and the affect of gravity was larger.

The space-time fabric, described by the second rank metric tensor has a similarity to an elastic fabric, described by the fourth rank elastic constant tensor. The metric tensor that describes the curvature of the space-time fabric is itself a function of the coordinate components of space-time. The elastic **constant** tensor is constant. The elastic fabric mode energy quanta are called Phonons. The electromagnetic field mode and space-time mode interactions are similar to the quantized electromagnetic field and acoustic mode interaction [9]. Because of this similarity the energy quanta of the space-time fabric modes are called “**gravity Phonons**”.

The gravity Phonons are massless Bosons, that propagate with the speed of light. Light Photons are derived from a vector model, the Maxwell Electromagnetic Theory, and have a spin angular momentum of 1. The gravity Phonons are derived from a tensor model, the GRT, and have a spin angular momentum of 2. The space-time deformation caused by the mass acts as a cavity to determine the frequency of the space-time fabric modes.

Before Ludwig Boltzmann [10] in 1896, continuous wave theories were used to formulate Statistical Thermodynamic models of acoustic and electromagnetic modes. But none of these formulations agreed with observations. First Boltzmann [10] and later Bose [11] used a discrete model of Statistical Thermodynamic employing quantized energy and obtained results in agreement with observations that are used until today. The most used formulas are the Boltzmann Entropy and the Bose-Einstein distribution function. In most of the Universe, except in

the vicinity of Black holes or Neutron stars, the space-time fabric is only slightly deformed.

Therefore, the gravity Phonons derived here can be used for the calculations of statistical Thermodynamic properties of the space-time fabric such as its average energy, entropy, pressure, and temperature (2.72503°K). The thermal energy of 0.2340247 meV of the Cosmic Background Radiation is much larger than the energy of a gravity Phonon of 0.59893 atto eV calculated here. The calculations of the Statistical Thermodynamic models are deferred to future publications.

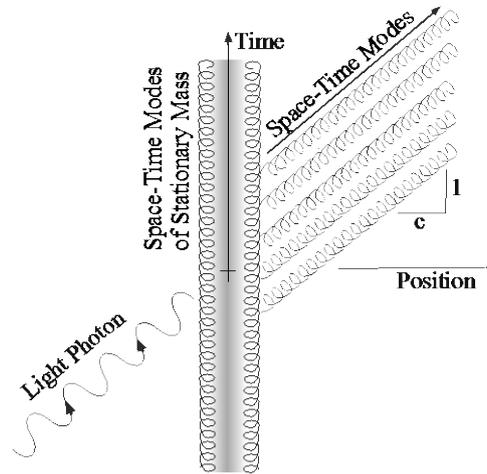
A. D. Sakharov [12] of the Sovietski Akademii Nauk (Soviet Academy of Science) and later H. E. Puthoff [13] postulated that gravity is not a basic force. It is a consequence of the electromagnetic force, where the electromagnetic force is generated by a Zero Point Fluctuation of the vacuum. The electromagnetic force can also be generated by a Zitterbewegung, Jitter Motion in German, of particles. However, we are not concerned with the basic phenomena that generate electromagnetic waves. But, like Sakharov and Puthoff, we are concerned with the contribution to the deformation of the space-time fabric by the energy of an electromagnetic wave.

Each light Photon generates a **shower of identical space-time modes**, see **Figure 1**. Each space-time mode can have any number of energy quanta, called gravity Phonons. Quantum Mechanics is a probabilistic model of Nature. The probability of generating a space-time mode shower is much larger than the probability of all the gravity Phonons collecting and generating a Photon. The entropy of the shower of gravity Phonons is much larger than the entropy of the electromagnetic wave that created the gravity Phonon shower. Therefore, this process has a **unique Arrow of Time**.

This Arrow of time is consistent with Arthur Stanley Eddington's [14] concept of the Arrow of Time. Another explanation for the discussion of the Arrow of Time, are in References [15] [16] and [17]. Stephen Hawking [18] discusses the Arrow of Time in "*The Beginning of Time*" based on the way the Universe developed. This is very different from the Arrow of Time of the gravity Phonons. The gravity Phonons model developed here is also not valid for the beginning of the Universe discussed by Hawking.

The reciprocal relationship between electromagnetic wave modes and gravity is similar to the reciprocal interaction between sound waves and gravity discussed by Nicolis and Penco [19] in "*Mutual Interaction of Photons, Rotons, and Gravity*" and A. Esposito [20] *et al.* in "*Gravitational Mass Carried by Sound Waves*". Instead of a reduction of the symmetry of the space-time fabric, they use a non-linear sound wave effect. The model described in this paper does not have to resort to Plank time or Plank length, or other exotic parameters.

An interesting approach to the interaction of Electromagnetic fields and deformations of the space-time fabric is discussed by Gerald E. Marsh [21] in "*Electromagnetic and Gravity Waves: The Third Dimension*". He uses the Lorenz force and the second-order equation of geodesic deviation followed by the



**Figure 1.** The annihilation of a light Photon generates a **shower of identical space-time modes**. Each space-time mode can have any number of energy quanta called **gravity Phonons**. A stationary Mass causes a distortion of the space-time fabric, which facilitates the interaction of the photon and the space-time modes. The distortion of space-time by the mass can also be expressed in terms of standing space-time waves. Also, both the light Photon and gravity Phonons propagate with the velocity of light. This derivation is for slightly curved space-time fabric only fields only.

introduction of a local inertial frame. In this paper, we also use a second-order expansion approach in our derivations.

Bryce C. DeWitt attempts to derive a Quantum theory of gravity from the GRT starting with a General Relativistic Lagrangian. His derivation is intended to be applicable for all gravity values. He wrote 3 papers [22] [23] [24] but he was unable to produce a Quantum Mechanical model of gravity in a form that has useful applications.

The model derived in my paper corresponds approximately to DeWitt's limit Hamiltonian  $H_\infty$  appearing in equation {4.9} on page 1119 of Quantum Theory of Gravity I. DeWitt is using the full tensor formulation of the GRT for his derivation. I use contractions with time-like unit vectors of the tensors in the GRT which results in a scalar formulation of the GRT. The contraction leaves only functions that were verified by astronomical observations or experiments because most of the tests that validated the GRT were based on calculations that reduced parameters of the GRT to scalars. This results in a description that is similar to an Empirical description of physical observations. Since my derivation is from equations validated by real physical observations and experiments it supersedes any difficulties that occur in the full quantization of the GRT.

Carlo Rovelli [25] in his paper “Notes for a Brief History of Quantum Gravity” describes in detail the history of formulizing Quantum gravity in the time period from 1930 to 2001. Rovelli describes three main approaches to the formulation of Quantum Gravity.

The FIRST attempt was to formulate a quantum field theory of the fluctuations of the metric on a classical flat Minkowski space. Even though Van Nieu-

wenhuizen, and others, found firm evidence of a non-renormalizability model, a search for an extension of the GRT using a renormalizable perturbation expansion was started. A high order derivative theory and supergravity theory converged successfully to string theory.

The SECOND was an attempt to construct a quantum theory in which the Hilbert space carries a representation of the operators corresponding to the full metric, or some functions of the metric, without a background metric to be fixed. The formal equations of the quantum theory were successfully formulated with loop quantum gravity.

The THIRD was an attempt to use some version of Feynman's functional integral quantization to define the theory. This is somewhat similar to the approach used in this paper.

The paper "*Potential Origin of a Quantitive Equivalence between Gravity and Light*" by Michael A. Persinger [26] is even more speculative. It invokes a mass of the Photon and the mass of the universe to calculate the pressure of Photons in the Universe.

The research described above and in references [21] through [27] are attempts to formulate a quantized gravity mode model that is generally applicable. The Quantized space-time fabric modes derived in this manuscript, are based only on an interaction of an electromagnetic wave and a weak gravitational field. It does not require renormalization and is not based on String Theory or Loop Quantum Gravity [25] [28]. The model of space-time fabric quantization described in Chapter V of this paper is used for the calculation of the gravity Photon generation rate by Solar radiation.

## 2. Reciprocal Interaction of Space-Time Modes and a Light Wave

**NOTE:** This derivation is only valid for slightly curved space-time fabric.

The effect of the curvature of the space-time fabric on a light wave is to deflect it as Einstein [1] described. To describe the affect of the energy of the light wave on the curvature of space-time, Einstein's equation is used. In Einstein's equation, the Einstein tensor describes the curvature of space-time, and the affect of the light wave energy is described by the electromagnetic stress tensor.

The deflection of a light wave by the curvature of space-time due to the Solar mass is calculated in Einstein's Chapter "*On the Influence of Gravitation on the Propagation of Light*" in section § 4 "*Bending of Light-Rays in the Gravitational Field*" on page 108 and page 168, equation {74}. The deflection angle [1]  $\theta_{\odot}$  is:

$$\text{a) } \theta_{\odot} = \frac{2M_{\odot}G}{c^2R_{\odot}} \quad \text{b) } \theta_{\odot} = \frac{r_{\odot\text{ss}}}{R_{\odot}} \quad \text{c) } \frac{r_{\odot\text{ss}}}{R_{\odot}} \equiv \text{Schwarzschild ratio} \quad (1)$$

Here  $M_{\odot}$  is the solar mass,  $R_{\odot} = 6.957 \times 10^8 \text{ m}$  is the radius of the Sun and  $r_{\odot\text{ss}} = 2954.030552 \text{ m}$  is its Schwarzschild [29] radius.  $G$  is Newton's gravitational constant.

$$r_{\odot\text{ss}} = \frac{2M_{\odot}G}{c^2} \quad (2)$$

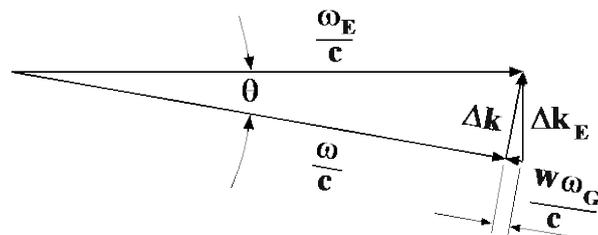
For the Sun the Schwarzschild ratio  $\frac{r_{\odot ss}}{R_{\odot}} = 4.246127 \times 10^{-6}$  and the deflection angle  $\theta_{\odot} = 0.8758266$  arc seconds. It was first measured by F. W. Dyson, A. S. Eddington, and C. Davidson [4] in 1919. Subsequent measurements have confirmed the value of the deflection angle. For the Earth  $r_{ss} = 8.869518$  mm is the Schwarzschild radius and  $R = 6.378 \times 10^6$  m is the radius. For the Earth, the Schwarzschild ratio  $\frac{r_{ss}}{R} = 1.390642 \times 10^{-9}$ . The deflection angle of a light beam  $\theta = 0.286841$  marc seconds which corresponds to slightly curved space-time.

The wave vector  $\frac{\omega_E}{c}$  of the light wave in the absence of gravity, the wave vector  $\frac{\omega}{c}$  of the light wave subject to gravity, and change in the wave vector  $\Delta k$  of the light wave due to the deflection by gravity form the large triangle in **Figure 2**. Similar to equation 1b, this deflection angle  $\theta$  is approximately equal to the Schwarzschild ratio  $\frac{r_{ss}}{R}$ .

$$a) \sin\theta = \frac{c\Delta k}{\omega_E} \quad b) \theta \approx \frac{c\Delta k}{\omega_E} \quad c) \frac{r_{ss}}{R} \approx \frac{c\Delta k}{\omega_E} \quad d) \Delta k \approx \frac{r_{ss}\omega_E}{cR} \quad (3)$$

Dadhigh Naresh [6] writes in “*Subtle is the Gravity*” Section 5, that since energy and mass are equivalent in the GRT, the energy of the light wave also contributes to the curvature of the space-time fabric. The affect of the light electromagnetic wave on the curvature of space-time can be calculated from Einstein’s equation [5]. To date, all astronomical observations and experimental measurements have verified the accuracy of the GRT. The affect of the energy of the light wave on the curvature of space-time is very small. I could not find any astronomical observation or experimental measurements of this affect. However, since the affect is predicted by the GRT which has been proven correct in all its tests, the affect of the energy of the light wave on the curvature of space-time must also be valid.

$$a) \frac{c^4}{8\pi G} E_{\mu\nu} = T_{\mu\nu} \quad \text{where} \quad b) E_{\mu\tau} = R_{\mu\tau} - \frac{1}{2} g_{\mu\tau} R \quad (4)$$



**Figure 2.** Derived here are wave vector triangles, which express the conservation of momentum. The large right triangle describes the affect of the curvature of space-time on the light wave, and the small right triangle describes the affect of the energy of the light wave on the curvature of space-time to within a constant w.

$E_{\mu\nu}$  is the Einstein tensor derived from the Ricci tensor  $R_{\mu\nu}$ .  $T_{\mu\tau}$  is the electromagnetic part of the stress-energy tensor. Here  $g_{\mu\tau}$  is the metric tensor. The Ricci tensor is derived by a contraction over the indices  $\rho$  and  $\sigma$  of the Riemann-Christoffel tensor  $B_{\mu\sigma\rho}^{\rho}$ . The curvature of space-time is described by the Riemann-Christoffel tensor. Equation (4) is a tensor equation. It can be reduced to a scalar equation for slightly curved space-time fabric only by contracting Equation (4) with a time like unit vector with components  $u^{\mu}$ .

$$\begin{aligned} \text{a) } & \frac{c^4}{8\pi G} \left[ R_{\mu\tau} u^{\mu} u^{\tau} - \frac{1}{2} g_{\mu\tau} u^{\mu} u^{\tau} R \right] = T_{\mu\tau} u^{\mu} u^{\tau} \\ \text{b) } & -\frac{c^4}{8\pi G} R_{tt} \approx T_{tt} \\ \text{c) } & \frac{c^4}{8\pi G} \text{Curvature} = \text{Electromagnetic energy density function} \end{aligned} \tag{5}$$

Summation over repeated Greek indices is implied. No summation over the Latin indices  $t$  is implied.  $E_{tt}$  and  $T_{tt}$  are the  $tt$  components of the Einstein tensor and Stress Energy tensor. Here the  $T_{tt}$  component of the Stress Energy tensor is equal to the electromagnetic energy density function. The timelike unit vector  $u^{\mu}$  is:

$$u^{\mu} = [-1 \ 0 \ 0 \ 0] \tag{6}$$

The development of Einstein's equation resulting in Equation (5b) is described in detail by Lee Loveridge in "*Physical and Geometric Interpretations of the Riemann Tensor, Ricci Tensor and Scalar Curvature*", Reference 5. Loveridge gives an excellent description of the derivation of the Einstein equation from the concept of curvature of space-time, the Riemann-Christoffel Tensor, and the Ricci Tensor. Loveridge uses the sum over the coordinates of a large number of point particles in the vicinity of the original point particle under consideration. Summing over a large number of particles is equivalent to the contraction of the Riemann-Christoffel tensor to form the Ricci tensor. Instead of describing the motion of a single point particle one has now to describe the motion of a volume  $\delta V$  of all the point particles in the vicinity of the original point particle. From Loveridge's [5] equation {7} one can express the left side of Equation (5b), in the form of second time derivatives of the volume  $\delta V$  in a three-dimensional space.

$$-\frac{c^4}{4\pi G} \left[ \frac{1}{V_0} \frac{D^2 \delta V}{c^2 dt^2} - \frac{1}{V_0} \frac{D^2 \delta V_{\text{Mass only}}}{c^2 dt^2} \right] = Q(t) \tag{7}$$

where  $Q(t)$  is the electromagnetic energy density function. Loveridge also derives Newton's laws from the Einstein equation, Equation (4). The electromagnetic energy density function  $Q(t)$  in the real world is a function of space and time. A constant and uniform electromagnetic energy density would result in a constant, uniform and therefore, isotropic space-time fabric deformation. But the electromagnetic field does not interact with an isotropic space-time fabric.  $Q(t)$  can be expressed as a Fourier Integral.

$$-\frac{c^4}{4\pi G} \left[ \frac{1}{V_0} \frac{D^2 \delta V}{c^2 dt^2} - \frac{1}{V_0} \frac{D^2 \delta V_{\text{Mass only}}}{c^2 dt^2} \right] = \int_{-\infty}^{\infty} d\psi \frac{\hbar \Delta k(\psi) c}{V_0} q(\psi) \exp(j\psi t) \quad (8)$$

where  $j = \sqrt{-1}$ . Here  $q(\psi)$  is a dimensionless Fourier Integral of the electromagnetic energy density function and  $\psi$  is a frequency. A detailed derivation of the electromagnetic stress tensor and its contraction is derived in **Appendix A**. Equation (A4b) is used in the argument of the Fourier integral on the right sides of Equations (8). Expressing the incremental volume  $\delta V$  also as Fourier integrals.

- a) For curved space-time  $\delta V = \int_{-\infty}^{\infty} d\psi V(t) \exp(j\psi t)$  (9)
- b) For curved space-time due to mass only  $\delta V_{\text{Mass only}} = \int_{-\infty}^{\infty} d\psi V_0 \exp(j\psi t)$

where  $V(t)$  is a very slow varying function of time. By substituting Equations (9) into Equation (8).

$$-\frac{c^2}{4\pi G} \left[ \frac{D^2}{dt^2} \int_{-\infty}^{\infty} \frac{V(t)}{V_0} \exp(j\psi t) d\psi - \frac{D^2}{dt^2} \int_{-\infty}^{\infty} \exp(j\psi t) d\psi \right] = \int_{-\infty}^{\infty} d\psi \frac{\hbar \Delta k(\psi) c}{V_0} q(\psi) \exp(j\psi t) \quad (10)$$

Performing first, the differentiation of the terms in the square bracket of Equation (10). The volume amplitude  $V(t)$  in the first Fourier Integral in the square bracket of Equation (10) is a very slow varying function of time compared to the oscillation. Therefore, it is treated as a constant in the Fourier Integral. Taking the inverse Fourier Integral:

$$\frac{c^2}{4\pi G} \left[ -\frac{\ddot{V}}{V_0} - 2j \frac{\omega_G \dot{V}}{V_0} + \frac{\omega_G^2 V}{V_0} - \omega_G^2 \right] = \frac{\hbar \Delta k(\omega_G) c}{V_0} q(\omega_G) \quad (11)$$

where  $\omega_G$  is an oscillating frequency of a Fourier component of the incremental volume  $\delta V$ . Therefore,  $\omega_G$  is also an oscillating frequency of the space-time fabric modes. Since the volume  $V(t)$  is a very slow varying function of time, the first term in the square bracket of Equation (11) has been neglected. The Volume  $V$  in the third term in the square bracket of Equation (11) was approximated by  $V_0$ . Collecting the remaining terms of Equation (11).

$$-j \frac{c^2 \omega_G}{2\pi G} \frac{\dot{V}}{V_0} = \frac{\hbar \Delta k(\omega_G) c}{V_0} q(\omega_G) \quad (12)$$

Assuming the volume  $V$  has also a harmonic time dependence. Therefore, one can approximate the first time derivative  $\dot{V}$  of  $V$  in Equation (12) by:

$$\dot{V} \equiv j \frac{2\pi G \hbar q}{c^2} w \frac{R}{r_{ss}} \quad (13)$$

where  $\frac{2\pi G \hbar R}{c r_{ss}} = 1.060763 \times 10^{-43} \text{ m}^3/\text{second}$  and where the dimensionless constant  $w$  will have to be evaluated from observations. Substituting Equation (13) into Equation (12).

$$\Delta k = w \frac{R\omega_G}{r_{ss}c} \quad (14)$$

The disturbance of the space-time fabric with wave vector  $\frac{\omega_G}{c}$  propagates in the opposed direction to the deflected wave, see **Figure 2**. The smaller triangle of **Figure 2** is illustrated by Equation (14), describes the affect of the energy of the light wave on the curvature of space-time to within a constant  $w$ . The large triangle of **Figure 2** describes the affect of the curvature of space-time on the light wave. By substituting Equation (14) into Equation (3d) one obtains for the ratio of the oscillating frequency  $\omega_G$  of the space-time fabric mode and the frequency  $\omega_E$  of the light in the absence of gravity.

$$\text{a) } \frac{\omega_G}{c} \frac{wR}{r_{ss}} \approx \frac{r_{ss}\omega_E}{cR} \quad \text{b) } \frac{\omega_G}{\omega_E} \approx \frac{r_{ss}^2}{wR^2} \quad (15)$$

For the Earth  $\frac{r_{ss}^2}{R^2} = 1.938138404 \times 10^{-18}$  is as expected, a very small number.

**Equations (3) and (14) describe the reciprocal relationship of the light wave and the space-time fabric.** Equation (15b) describes the combined affect of the space-time curvature acting on the light wave and the energy of the light wave acting on the space-time curvature.

### 3. The Relationship between the Frequency of the Light Wave Subject to Gravity, the Frequency of the Light Wave Not Subject to Gravity and the Frequency of the Space-Time Modes

The electromagnetic energy density is employed for deriving a Hamiltonian of the electromagnetic mode and space-time fabric modes in second quantized form. The electromagnetic energy density has a quadratic form in the components  $F_{\mu\nu}$  of the electromagnetic field tensor. Therefore, in order to derive the Hamiltonian, a quadratic form of a function of the small Schwarzschild ratio  $\frac{r_{ss}}{R}$  is obtained from a Taylor series expansion of the gravitational time dilation [1] equation.

The other General Relativistic affect used, is that clocks run slower when closer to the center of gravity of a mass than at larger distances from the mass [1] [7]. Clocks use oscillators, such as pendulums or vibrating crystals as the timing elements. Thus, the frequency of an oscillator is lower when closer to the center of gravity of a mass. The oscillating frequency of the light wave behaves like the oscillating frequency of the clock oscillators. This affect has been experimentally verified by measuring the gravitational blue shift of the frequency of gamma rays emitted by iron  $^{57}\text{Fe}$  by R. V. Pound and J. L. Sinder [7].

This change of frequency can be calculated from the time dilation. The time dilation was calculated by Einstein [1] in the chapter “*The Foundation of the GRT*” section §22 “*Behavior of Rods and Clocks in the Static Gravitational Field.*”

*Bending of Light Rays. Motion of the Perihelion of a Planetary Orbit.*” on page 160 using  $g_{44}$  from equation {70}. This equation for  $g_{44}$  is also the Schwarzschild metric [30] or Schwarzschild solution. The frequency  $\omega$  of a light wave in a gravitational field as a function of the frequency  $\omega_E$  of the light wave in the absence of the gravitational field  $\phi$  can be derived from the time dilation [1].

$$a) \omega = \frac{\omega_E}{\sqrt{1 - \frac{2\phi}{c^2}}} \text{ from ref. [31] } b) \phi = -\frac{MG}{R} \text{ resulting in } c) \omega \approx \frac{\omega_E}{\sqrt{1 + \frac{r_{ss}}{R}}} \quad (16)$$

Equation (16c) can also be calculated from the dilation of the oscillating period of a harmonic oscillator derived in “*Relativistic Harmonic Oscillator*” by Kirk T. McDonald [32] of the Joseph Henry Laboratory, of Princeton University. He calculated the time deletion of the period of oscillation of a mass and a spring oscillator in a gravitational field. When one reverses the approximation used to derive Professor McDonald’s equations {8} and {12} in his paper [32] one obtains Equation (16c). Another reference for the gravitational time dilation from which one can derive the function of the frequency  $\omega$  in a gravitational field, as a function of the frequency  $\omega_E$  of the light wave far from the mass in the absence of the gravitational field is given in “*Gravitational Time Dilation*” in Wikipedia [33]. Expanding Equation (16c) to second order in a Taylor series in the small parameter  $\frac{r_{ss}}{R}$  to obtain a quadratic equation.

$$\omega \approx \omega_E \left( 1 - \frac{r_{ss}}{2R} + \frac{3r_{ss}^2}{8R^2} + \dots \right) \quad (17)$$

This is the quadratic form of the function of the small Schwarzschild ratio  $\frac{r_{ss}}{R}$  discussed above.

The smaller the distance R, the closer the light wave is to the center of gravity of a mass, and the stronger is the affect of gravity acting on the light wave. The smaller the distance R, the lower the oscillating frequency  $\omega$  of the light wave. The light frequency is “Red Shifted”. Recall that in stronger gravity, clocks run slower, and the light wave oscillates slower.

Here  $\frac{r_{ss}}{R}$  represents the distortion of the curvature of the space-time fabric by the mass which facilitates the interaction of the light wave and the space-time fabric.

Substituting Equation (15b) into Equation (17) one obtains for the frequency  $\omega$  of the light wave near the surface of an Earth like mass:

$$a) \omega \approx \omega_E - \frac{\sqrt{w\omega_E\omega_G}}{2} + \frac{3w\omega_G}{8} + \dots$$

$$b) \omega \approx \left( \sqrt{\omega_E} - \frac{\sqrt{w\omega_G}}{4} \right)^2 + \frac{5w\omega_G}{16} \quad (18)$$

Putting the last term  $\frac{5w\omega_G}{16}$  of Equation (18b) temporarily aside, multiplying

the remaining equation by  $\hbar$  -Plank's constant divided by  $2\pi$ , and taking the square root.

$$\sqrt{\hbar\omega} \approx \sqrt{\hbar\omega_E} - \frac{\sqrt{\hbar w\omega_G}}{4} \tag{19}$$

The constant  $w$  in Equations (18) and (19) will have to be evaluated from observations.

#### 4. Formulation of the Second Quantized Form of the Space-Time Modes

Next, a second quantized Hamiltonian is derived from the square root of the energy  $\hbar\omega$  of the light wave in the presence of gravity of Equation (19), as a function of:

the square root of the energy  $\hbar\omega_E$  of the light wave in the absence of gravity, the energy  $\frac{\hbar w\omega_G}{16}$  of the space-time fabric modes,

and the energy term  $\frac{5w\hbar\omega_G}{16}$  that was set aside in Equation (18).

The Quantum Electrodynamics models described in “*Quantum Electronics*” by Amnon Yariv [34] in the section on “*Plane Wave Quantization*” equations {5.6.15} on page 98 are employed for the electric field vector operator  $\mathbf{E}(\omega)$  and the magnetic flux density pseudo vector operator  $\mathbf{B}(\omega)$  as functions of the light frequency in the presence of gravity. These operators are also described in reference [35] equations {2.12}, {2.13}, and {2.52}; and also in reference [36].

$$\begin{aligned} \text{a) } \mathbf{E}(\omega) &= j\hat{\mathbf{a}}_E S(\mathbf{r}) \sqrt{\frac{\hbar\omega}{2V\epsilon_0}} (\mathbf{a}e^{-jkz} - \mathbf{a}^\dagger e^{jkz}) \\ \text{and b) } \mathbf{B}(\omega) &= \hat{\mathbf{a}}_B S(\mathbf{r}) \sqrt{\frac{\hbar\omega\mu_0}{2V}} (\mathbf{a}e^{-jkz} + \mathbf{a}^\dagger e^{jkz}) \end{aligned} \tag{20}$$

where  $\epsilon_0$  is the dielectric constant of free space,  $\mu_0$  is the permeability of free space,  $\hat{\mathbf{a}}_x$  is a unit vector.  $S(\mathbf{r})$  is a normalized description of the space-time distribution of the electromagnetic field modes and  $V$  is the volume occupied by the light Photons. By substituting Equation (19) for  $\sqrt{\hbar\omega}$  into Equations (20).

$$\begin{aligned} \text{a) } \mathbf{E}(\omega) &= j\hat{\mathbf{a}}_E \sqrt{\frac{\hbar}{2V\epsilon_0}} \left[ S_E(\mathbf{r}) \sqrt{\omega_E} (\mathbf{a}e^{-jkz} - \mathbf{a}^\dagger e^{jkz}) - S_G(\mathbf{r}) \frac{\sqrt{w\omega_G}}{4} (\mathbf{b}e^{-jqz} - \mathbf{b}^\dagger e^{jqz}) \right] \\ \text{b) } \mathbf{B}(\omega) &= \hat{\mathbf{a}}_B \sqrt{\frac{\hbar\mu_0}{2V}} \left[ S_E(\mathbf{r}) \sqrt{\omega_E} (\mathbf{a}e^{-jkz} + \mathbf{a}^\dagger e^{jkz}) - S_G(\mathbf{r}) \frac{\sqrt{w\omega_G}}{4} (\mathbf{b}e^{-jqz} + \mathbf{b}^\dagger e^{jqz}) \right] \end{aligned} \tag{21}$$

where the form factors  $S_E$  and  $S_G$  are normalized.

$$\text{a) } 1 = \frac{1}{V} \int_{\text{Volume}} S_E S_E^* dv \quad \text{b) } 1 = \frac{1}{V} \int_{\text{Volume}} S_G S_G^* dv \tag{22}$$

The form factors  $S_E$  and  $S_G$  are calculated by using post-Newtonian Maxwell equations and the boundary conditions.

Photon mode operators  $\mathbf{a}$  and  $\mathbf{a}^\dagger$  are associated with the square root  $\sqrt{\hbar\omega_E}$  of the energy  $\hbar\omega_G$ , and gravity Phonon mode operators  $\mathbf{b}$  and  $\mathbf{b}^\dagger$  are associated with the square root  $\frac{\sqrt{w\hbar\omega_G}}{4}$  of the energy  $\frac{w\hbar\omega_G}{16}$ . The space-time energy quanta, gravity Phonons form a Hilbert space. The Photons also form a Hilbert space. The state raising and state lowering operators on these Hilbert spaces are defined as:

- $\mathbf{a}^\dagger$  is the light Photon number state raising operator;
- $\mathbf{a}$  is the light Photon number state lowering operator;
- $\mathbf{b}^\dagger$  is the gravity Phonon number state raising operator;
- $\mathbf{b}$  is the gravity Phonon number state lowering operator.

The state raising and state lowering operators, which operate on the light Photon and gravity.

Phonon number state wave functions  $|n\rangle$  and  $|m\rangle$ , are given below. Where  $n = 0, 1, 2, 3, 4, \dots$ ,  $m = 0, 1, 2, 3, 4, \dots$

$$\begin{aligned}
 \text{a) } \mathbf{a}^\dagger |n\rangle &= \sqrt{n+1} |n+1\rangle & \text{e) } \mathbf{b}^\dagger |m\rangle &= \sqrt{m+1} |m+1\rangle \\
 \text{b) } \mathbf{a} |n\rangle &= \sqrt{n} |n-1\rangle & \text{f) } \mathbf{b} |m\rangle &= \sqrt{m} |m-1\rangle \\
 \text{c) } \mathbf{a} |0\rangle &= 0 & \text{g) } \mathbf{b} |0\rangle &= 0 \\
 \text{d) } \langle n|k\rangle &= \delta_{nk} & \text{h) } \langle m|\ell\rangle &= \delta_{m\ell}
 \end{aligned}
 \tag{23}$$

The light Photon operators  $\mathbf{a}$  and  $\mathbf{a}^\dagger$  commute with the gravity Phonon operators.  $\mathbf{b}$  and  $\mathbf{b}^\dagger$ . The commutation relation for the light Photon operators  $\mathbf{a}$  and  $\mathbf{a}^\dagger$  as well as the commutation relation for the gravity Phonon operators  $\mathbf{b}$  and  $\mathbf{b}^\dagger$  are:

$$\text{a) } \mathbf{a}\mathbf{a}^\dagger - \mathbf{a}^\dagger\mathbf{a} = 1 \qquad \text{b) } \mathbf{b}\mathbf{b}^\dagger - \mathbf{b}^\dagger\mathbf{b} = 1
 \tag{24}$$

The electromagnetic energy density  $u$  is described by John David Jackson [37] in “*Classical Electrodynamics*”, Chapter 6, section 6.7 equation {6.106} on page 259, and by L. D. Landau and E. M. Lifshitz [38] in “*The Classical Theory of Fields*” equations {31.1} and {31.5} on page 76. The total electromagnetic energy  $U$  is:

$$\begin{aligned}
 \text{a) } U &= \frac{1}{2} \int_{\text{Volume}} \left( \frac{2}{\mu_0} \mathbf{F}_{0\beta} \mathbf{F}^{\beta 0} - \frac{1}{2\mu_0} \mathbf{F}_{\mu\alpha} \mathbf{F}^{\alpha\mu} \right) dv \\
 \text{b) } U &= \frac{1}{2} \int_{\text{Volume}} \left( \mathbf{E}_\alpha \mathbf{E}_\alpha \epsilon_0 + \frac{\mathbf{B}_\alpha \mathbf{B}_\alpha}{\mu_0} \right) dv
 \end{aligned}
 \tag{25}$$

where MKS units were used. The electromagnetic field tensor with components  $F^{\alpha\beta}$  is described by Jackson [37] in equation {11.137} on page 556, and by Landau and Lifshitz [38] equation {23.5} on page 61, and also in equations {5} and {6} of Reference [39]. Substituting equations 21 into equation 25b, similar to the derivation of the Hamiltonian of equation {5.6-10} by Yariv [34], to obtain the total Hamiltonian  $\mathbf{H}$  operator. The derivation of the Hamiltonian operator  $\mathbf{H}$  is performed in **Appendix B**.

Substituting Equations (24) into Equation (B3) of **Appendix B** for  $\mathbf{a}\mathbf{a}^\dagger$  and

$bb^\dagger$ , adding the term  $\frac{5\hbar\omega_G}{16}$  of Equation (18b), back in, and performing the integration using Equations (22).

$$\mathbf{H} = \hbar\omega_E \left[ \mathbf{a}^\dagger \mathbf{a} + \frac{1}{2} \right] - \frac{1}{V_{\text{Int}}} \int_{\text{Int. Vol.}} dv \frac{S_G S_E^* + S_E S_G^*}{2} \frac{\hbar\sqrt{w\omega_E\omega_G}}{2} \left[ \mathbf{b}^\dagger \mathbf{a} e^{-j(k-q)z} + \mathbf{b} \mathbf{a}^\dagger e^{j(k-q)z} \right] + \frac{\hbar\omega_G}{8} \left[ \mathbf{b}^\dagger \mathbf{b} + 3 \right] \quad (26)$$

Equation (26) represents the three terms of Equations (17) and (18a). Equation (26) contains three sub Hamiltonian operators, an Electromagnetic wave Hamiltonian operator  $\mathbf{H}_E$ , an Interaction Hamiltonian operator  $\mathbf{H}_{\text{Int}}$ , and a gravity wave Hamiltonian operator  $\mathbf{H}_G$  :

a)  $\mathbf{H}_E = \hbar\omega_E \left[ \mathbf{a}^\dagger \mathbf{a} + \frac{1}{2} \right]$   
 b)  $\mathbf{H}_{\text{Int}} = \frac{-1}{V_{\text{Int}}} \int_{\text{Int. Vol.}} dv \frac{S_G S_E^* + S_E S_G^*}{2} \hbar\omega_G \left[ (N_G \mathbf{b}^\dagger) \mathbf{a} e^{-j(k-q)z} + (N_G \mathbf{b}) \mathbf{a}^\dagger e^{j(k-q)z} \right]$   
 c)  $\mathbf{H}_G = \frac{\hbar\omega_G}{8} \left[ \mathbf{b}^\dagger \mathbf{b} + 3 \right]$

(27)

Equation (27b) implies that each Photon interacts with  $N_G$  fold degenerate space-time fabric modes. Each of these space-time fabric modes can have any number  $m$  of energy quanta, gravity Phonons. The number  $N_G$  is derived from the term  $\frac{\sqrt{w\omega_G\omega_E}}{2}$  in Equations (18a) divided by  $\omega_G$  and Equation (15b).

$$\text{a) } \frac{\sqrt{w\omega_G\omega_E}}{2w\omega_G} = \frac{1}{2} \sqrt{\frac{\omega_E}{w\omega_G}} \quad \text{b) } \frac{1}{2} \sqrt{\frac{\omega_E}{w\omega_G}} = \frac{R}{2r_{ss}} \quad \text{c) } N_G \approx \frac{\sqrt{wR}}{2r_{ss}} \quad (28)$$

For an Earth-like mass  $N_G = 1.79773024 \times 10^8$ . The quantity  $S_G S_E^* + S_E S_G^*$  is always real. The two operators in the Interaction Hamiltonian operator  $\mathbf{H}_{\text{Int}}$  of Equation (27b) describe the reciprocal actions of the electromagnetic and gravity waves. The terms in the Interaction Hamiltonian operator  $\mathbf{H}_{\text{Int}}$  define; either that a light Photon is annihilated and  $N_G$  identical gravity Phonon modes are created in a forward traveling wave  $e^{-j(k-q)z}$ , or  $N_G$  gravity Phonons spontaneously assemble and are annihilated, and a light Photon is created in a reverse traveling wave  $e^{j(k-q)z}$ . Therefore, each light Photon generates a **shower of  $N_G$  identical space-time modes**, see **Figure 1**. Each space-time mode can have any number of energy quanta, gravity Phonons.

The Interaction of the electromagnetic wave and gravity wave are restricted to the volume where both are present. This is the Interaction volume  $V_{\text{Int}}$ .

Quantum mechanics is a probabilistic model of Nature. The probability that a light Photon is annihilated and  $N_G$  gravity Phonons are created, is much larger than the probability that all  $N_G$  gravity Phonons will spontaneously assem-

ble and create a light photon. **This process exhibits a unique Arrow of Time** [15] [17]. From Equation (27c) the gravity Phonon ground state is:

$$\langle 0 | \mathbf{H}_G | 0 \rangle = \frac{3w}{8} \hbar \omega_G \tag{29}$$

The total energy and momentum before and after the interaction must also be conserved.

$$\hbar \omega = \hbar \omega_E - N_G \hbar \omega_G + \frac{3w}{8} \hbar \omega_G \tag{30}$$

where  $\omega$  of Equation (18) is the frequency in the presence of gravity. Substituting Equation (15b) for  $\omega_G$  into Equation (30).

$$\hbar \omega = \hbar \omega_E \left( 1 - \frac{r_{ss}}{2R} + \frac{3r_{ss}^2}{8R^2} \right) \tag{31}$$

Equation (31) is in agreement with Equation (17).

### 5. Calculation of the Gravity Phonon Generation Rate

Fermi's Golden Rule is employed to calculate the average rate  $\frac{1}{\tau(\omega_E)}$  at which the light from the Sun generates gravity Phonon modes with frequency  $\omega_G$ . Fermi's Golden Rule was derived by Enrico Fermi [40] using time dependent perturbation theory in "Nuclear Physics", and described in "Quantum Mechanics" by Eugene Merzbacher [41] Chapter 19 equation {19.99}.

$$\frac{1}{\tau(\omega_E)} = \frac{2\pi}{\hbar} \rho(\omega_E) |\langle 1 | \langle N_{Sun} - 1 | \mathbf{H}_{Int} | N_{Sun} \rangle | 0 \rangle|^2 \tag{32}$$

Here  $\langle 1 | \langle N_{Sun} - 1 | \mathbf{H}_{Int} | N_{Sun} \rangle | 0 \rangle$  is an interaction matrix element, where  $|N_{Sun}\rangle$  is the Photon number state wave function for  $N_{Sun}$  Solar radiation generated light Photons, and  $|0\rangle$  is the initial gravity Phonon number state wave function. Here  $\rho(\omega_E)$  is the density of states per unit Photon energy  $\hbar \omega_E$  per unit volume.

$$\text{a) } \rho(\omega_E) = \frac{1}{V} \frac{dn}{d(\hbar \omega_E)} f(\hbar \omega_E) \quad \text{b) } \rho(\omega_E) = \frac{\omega_E^2}{2\pi^2 \hbar c^3} \frac{1}{\exp\left(\frac{\hbar \omega_E}{kT}\right) - 1} \tag{33}$$

The Bose-Einstein distribution function [11] is included with the density of states. The Interaction Hamiltonian of Equation (27b) includes the integral over the interaction volume. Substituting Equation (27b) and Equation (33b) into Equation (32) to obtain the gravity Phonon generation rate  $\frac{1}{\tau(\omega)}$ . The term in

Equation (27b) that annihilates  $N_G$  gravity Phonons and generates a light Photon is neglected. The gravity Phonon Generation Rate is:

$$\frac{1}{\tau(\omega_E)} = \frac{V_{Int} \omega_E^2 \omega_G^2 N_G^2 N_{Sun}}{\pi c^3 \left[ \exp\left(\frac{\hbar \omega_E}{kT_{Sun}}\right) - 1 \right]} \tag{34}$$

The following data is used:

$\omega_E = 3.755898 \times 10^{15}$  radians per second, the frequency at the peak of the black body radiation curve for a solar temperature  $T_{\text{Sun}}$  of  $5778^\circ\text{K}$ .

$\omega_G = 0.0072634797$  radians per second calculated from Equation (15b), corresponding to a gravity wave wavelength of  $2.593318 \times 10^{11}$  m or 1.733526 A.U.

$N_G = 3.591514389 \times 10^8$  calculated from Equations (28c).

The top of the Earth atmosphere receives a Solar radiation energy density of  $1361 \text{ W/m}^2$ . This results in a Photon density  $N_{\text{Sun}} = 1.144981 \times 10^{13}$  Photons/ $\text{m}^3$ .

Setting the value of the constant  $w$  equal to 1. By substituting the numerical values into equation 34 one obtains:

$$\frac{1}{\tau(\omega_E)} = 9.143898 \times 10^{28} \text{ m}^{-3} \cdot \text{sec}^{-1} \quad \text{and} \quad \tau(\omega_E) = 1.093626 \times 10^{-29} \text{ sec} \cdot \text{m}^3. \quad \text{By}$$

comparison, the Plank time  $t_p = \sqrt{\frac{\hbar G}{c^5}} \approx 5.391159 \times 10^{-44} \text{ sec}$ .

## 6. Conclusions

Einstein [1] theorized in 1916 that a test mass travels towards a mass not because it is attracted by a force that acts across a distance, but because the test mass travels through space and time that is warped by mass and energy. A light Photon will not interact to first order with flat space-time, the ordinary four-dimensional Minkowski space. The Earth-like mass is used to remove this symmetry and facilitate the interaction of the Photon with warped space-time. **In this paper, the Interaction of a light Photon with a space-time fabric that has been deformed by this non-rotating Earth-like mass is described. The derivation is only for a slightly curved space-time fabric.**

Einstein also postulated the existence of wave modes in the space-time fabric. This has been verified by the LIGO experiment [2]. The interaction of a Photon with the space-time fabric generates space-time modes. Each space-time mode can have any number of energy quanta, called **gravity Phonons**. Gravity Phonons are tensor waves, they are Bosons, they have a spin angular momentum of 2, and propagate with the speed of light. In this example, the space-time quanta have an energy of 0.59893 atto eV and a wavelength of 1.7298 A.U.

Slightly curved space-time fabric implies that the escape velocity of a test mass from the surface of a mass under consideration is much less than the velocity of light. It also implies that the space-time fabric mode caused by the mass can expand with the velocity of light to a size that is much larger than the mass.

The curvature of space-time deflects an electromagnetic wave. The energy of the electromagnetic wave also contributes to the curvature of space-time. Thus, there is a reciprocal relationship between an electromagnetic wave mode and space-time fabric modes. Second quantization is employed to formulate the space-time fabric energy quanta. Each mode can have any number of energy quanta called **gravity Phonons**. The Phonon number state wave functions form a Hilbert space. The gravity Phonons propagate with the speed of light and are

massless Bosons. Since the gravity **Phonons are tensor waves**, they have spin angular momentum 2. The shape of the deformation of space-time and the Photon frequency  $\omega_E$  determine the space-time fabric mode frequency  $\omega_G$ .

As of this date, 29 October 2019, there now exists quantized models for all four forces, a Gravity Force for slightly deformed space-time fabric, the Electromagnetic Force, the Weak Nuclear Force and the Strong Nuclear Force of the standard model of Physics. The gravity Phonons can, among other applications, be used to calculate the Statistical Thermodynamic quantities of the space-time fabric such as its average energy, entropy, pressure, and temperature (2.72503°K), etc. The space-time mode quanta have only an energy of 0.59893 atto eV and the thermal energy of the Cosmic Background Radiation (CBR) in the Universe at a temperature of 2.72503°K has a thermal energy of 0.23482478 meV. Therefore, the ratio of the space-time mode quanta energy of equation 29 to the thermal energy of the CBR is only  $2.55054 \times 10^{-15}$ . Thus, the Ideal Gas Law should hold for the Universe modeled as a gas, with the galaxies as molecules.

It should be possible to verify this model by observations since its derivation is based on astronomical observations and experiments.

Each gravity Phonon has an energy of only 0.6 atto eV. The annihilation of a light Photon generates a shower of 36,000,000 identical space-time modes. Each space-time mode can have any number of energy quanta gravity Phonons. This interaction has two forms. The Photon can generate 36,000,000 space-time modes, or the 36,000,000 space-time modes can assemble and create a Photon. Quantum Mechanics is a probabilistic model of Nature. The probability of a Photon generating a large number of gravity Phonons is much larger than the probability of a large number of gravity space-time modes assembling and form a Photon. Therefore, this process exhibits a **Unique Arrow of Time**. That is, the **Unique Arrow of Time** is a consequence of a large number of gravity Phonons necessary to create a light Photon because gravity is such a weak force.

**A quantized model of space-time modes and their properties for slightly curved space-time fabric only has been derived in this paper.**

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## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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### Appendix A

The electromagnetic field tensor described here is only valid for gravity-free space. However, since small terms describing slightly curved space-time fabric are employed with this field tensor, and any slightly curved space-time fabric affects included in the field tensor would result in a second order affect, which is neglected. The contravariant Electromagnetic field tensor with components  $F^{\mu\nu}$  and the covariant Electromagnetic field tensor with components  $F_{\mu\nu}$  are:

$$\text{a) } F^{\mu\nu} = \begin{bmatrix} 0 & -\frac{E_1}{c} & -\frac{E_2}{c} & -\frac{E_3}{c} \\ \frac{E_1}{c} & 0 & -B_3 & B_2 \\ \frac{E_2}{c} & B_3 & 0 & -B_1 \\ \frac{E_3}{c} & -B_2 & B_1 & 0 \end{bmatrix} \quad \text{b) } F_{\mu\nu} = \begin{bmatrix} 0 & \frac{E_1}{c} & \frac{E_2}{c} & \frac{E_3}{c} \\ -\frac{E_1}{c} & 0 & -B_3 & B_2 \\ -\frac{E_2}{c} & B_3 & 0 & -B_1 \\ -\frac{E_3}{c} & -B_2 & B_1 & 0 \end{bmatrix} \quad (\text{A1})$$

The electromagnetic stress tensor with components  $T_{\mu\nu}$  is a function of the electromagnetic field tensor  $F_{\mu\nu}$ .

$$T_{\mu\nu} = \frac{1}{\mu_0} \left[ F_{\mu}^{\alpha} F_{\alpha\nu} - \frac{1}{4} \delta_{\eta\nu} \text{Tr}(F_{\mu}^{\alpha} F_{\alpha\nu}) \right] \quad (\text{A2})$$

Substituting Equations (A1) into Equation (A2)

$$T_{\mu\nu} = \frac{1}{\mu_0} \left\{ \begin{array}{cccc} \left[ \frac{E_1^2 + E_2^2 + E_3^2}{c^2} & -\frac{E_2 B_3 - E_3 B_2}{c} & \frac{E_1 B_3 - E_3 B_1}{c} & -\frac{E_1 B_2 - E_2 B_1}{c} \right] \\ \frac{E_2 B_3 - E_3 B_2}{c} & \frac{E_1^2}{c^2} - B_3^2 - B_2^2 & \frac{E_1 E_2}{c^2} + B_1 B_2 & \frac{E_1 E_3}{c^2} + B_1 B_3 \\ -\frac{E_1 B_3 - E_3 B_1}{c} & \frac{E_1 E_2}{c^2} - B_1 B_2 & \frac{E_2^2}{c^2} - B_3^2 - B_1^2 & \frac{E_3 E_2}{c^2} + B_3 B_2 \\ \frac{E_1 B_2 - E_2 B_1}{c} & \frac{E_1 E_3}{c^2} - B_1 B_3 & \frac{E_3 E_2}{c^2} - B_3 B_2 & \frac{E_3^2}{c^2} - B_2^2 - B_1^2 \end{array} \right\} \\
 - \frac{1}{2} \left[ \frac{E_1^2 + E_2^2 + E_3^2}{c^2} - B_1^2 - B_2^2 - B_3^2 \right] \left\{ \begin{array}{cccc} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{array} \right\} \quad (\text{A3})$$

Contracting the electromagnetic stress tensor  $T_{\mu\nu}$  of Equation (A3) with time-like unit vectors  $[-1 \ 0 \ 0 \ 0]$  with components  $u^{\mu}$  to obtain the energy density.

$$\text{a) } T_{\mu\nu} u^{\mu} u^{\nu} = \frac{1}{2} \left[ \epsilon_0 E_a E_a + \frac{B_a B_a}{\mu_0} \right], \text{ a} = 1, 2, 3 \quad \text{b) } T_{\mu\nu} u^{\mu} u^{\nu} \approx \frac{\hbar \Delta k c}{V_0} \quad (\text{A4})$$

where the time-like unit vector  $u^{\mu}$  is given by Equation (6). For the special case when the cross product of the electric field vector and the magnetic flux density

pseudo vector are equal to zero:

$$\mathbf{E} \times \mathbf{B} = 0 \tag{A5}$$

The electromagnetic stress tensor takes the form:

$$T_{\mu\nu} = \frac{1}{\mu_0} \left\{ \begin{array}{l} \left[ \begin{array}{cccc} \frac{E_1^2 + E_2^2 + E_3^2}{c^2} & 0 & 0 & 0 \\ 0 & \frac{E_1^2}{c^2} - B_3^2 - B_2^2 & \frac{E_1 E_2}{c^2} + B_1 B_2 & \frac{E_1 E_3}{c^2} + B_1 B_3 \\ 0 & \frac{E_1 E_2}{c^2} - B_1 B_2 & \frac{E_2^2}{c^2} - B_3^2 - B_1^2 & \frac{E_3 E_2}{c^2} + B_3 B_2 \\ 0 & \frac{E_1 E_3}{c^2} - B_1 B_3 & \frac{E_3 E_2}{c^2} - B_3 B_2 & \frac{E_3^2}{c^2} - B_2^2 - B_1^2 \end{array} \right] \\ -\frac{1}{2} \left[ \frac{E_1^2 + E_2^2 + E_3^2}{c^2} - B_1^2 - B_2^2 - B_3^2 \right] \left\{ \begin{array}{l} [1 \ 0 \ 0 \ 0] \\ [0 \ 1 \ 0 \ 0] \\ [0 \ 0 \ 1 \ 0] \\ [0 \ 0 \ 0 \ 1] \end{array} \right\} \end{array} \right\} \tag{A6}$$

## Appendix B

Substituting Equations (21) into Equation (25b) to obtain the total Hamiltonian  $\mathbf{H}$  operator.

$$\begin{aligned} \mathbf{H} = \int_{\text{Vol.}} dV & \left\{ \frac{-\hbar}{4V} \left[ S_E(\mathbf{r})\sqrt{\omega_E} (a e^{-jkz} - a^\dagger e^{jkz}) - S_G(\mathbf{r})\frac{\sqrt{\omega_G}}{4} (b e^{-jqz} - b^\dagger e^{jqz}) \right] \right. \\ & \times \left[ S_E^*(\mathbf{r})\sqrt{\omega_E} (a e^{-jkz} - a^\dagger e^{jkz}) - S_G^*(\mathbf{r})\frac{\sqrt{\omega_G}}{4} (b e^{-jqz} - b^\dagger e^{jqz}) \right] \\ & + \frac{\hbar}{4V} \left[ S_E(\mathbf{r})\sqrt{\omega_E} (a e^{-jkz} + a^\dagger e^{jkz}) - S_G(\mathbf{r})\frac{\sqrt{\omega_G}}{4} (b e^{-jqz} + b^\dagger e^{jqz}) \right] \\ & \left. \times \left[ S_E^*(\mathbf{r})\sqrt{\omega_E} (a e^{-jkz} + a^\dagger e^{jkz}) - S_G^*(\mathbf{r})\frac{\sqrt{\omega_G}}{4} (b e^{-jqz} + b^\dagger e^{jqz}) \right] \right\} \end{aligned} \quad (\text{B1})$$

Multiplying out Equation (B1)

$$\begin{aligned} \mathbf{H} = \frac{1}{V} \int_{\text{Vol.}} dV & \frac{\hbar}{4} \left\{ S_E S_E^* \omega_E \left[ -a a e^{-j2kz} + a^\dagger a + a a^\dagger - a^\dagger a^\dagger e^{j2kz} \right] \right. \\ & + S_G S_E^* \frac{\sqrt{\omega_E \omega_G}}{4} \left[ b a e^{-j(k+q)z} - b^\dagger a e^{-j(k-q)z} - b a^\dagger e^{j(k-q)z} + b^\dagger a^\dagger e^{j(k+q)z} \right] \\ & + S_E S_G^* \frac{\sqrt{\omega_E \omega_G}}{4} \left[ a b e^{-j(k+q)z} - a^\dagger b e^{j(k-q)z} - a b^\dagger e^{-j(k-q)z} + a^\dagger b^\dagger e^{j(k+q)z} \right] \\ & + S_G S_G^* \frac{\omega_G}{16} \left[ -b b e^{-j2qz} + b^\dagger b + b b^\dagger - b^\dagger b^\dagger e^{j2qz} \right] \\ & + S_E S_E^* \omega_E \left[ a a e^{-j2kz} + a^\dagger a + a a^\dagger + a^\dagger a^\dagger e^{j2kz} \right] \\ & + S_G S_E^* \frac{\sqrt{\omega_E \omega_G}}{4} \left[ -b a e^{-j(k+q)z} - b^\dagger a e^{-j(k-q)z} - b a^\dagger e^{j(k-q)z} - b^\dagger a^\dagger e^{j(k+q)z} \right] \\ & + S_E S_G^* \frac{\sqrt{\omega_E \omega_G}}{4} \left[ -a b e^{-j(k+q)z} - a^\dagger b e^{j(k-q)z} - a b^\dagger e^{-j(k-q)z} - a^\dagger b^\dagger e^{j(k+q)z} \right] \\ & \left. + S_G S_G^* \frac{\omega_G}{16} \left[ b b e^{-j2qz} + b^\dagger b + b b^\dagger + b^\dagger b^\dagger e^{j2qz} \right] \right\} \end{aligned} \quad (\text{B2})$$

Collecting terms.

$$\begin{aligned} \mathbf{H} = \frac{1}{2V} \int_{\text{Vol.}} dV & \left\{ S_E S_E^* \hbar \omega_E \left[ a^\dagger a + a a^\dagger \right] \right. \\ & - \frac{S_G S_E^* + S_E S_G^*}{2} \frac{\hbar \sqrt{\omega_E \omega_G}}{2} \left[ b^\dagger a e^{-j(k-q)z} + b a^\dagger e^{j(k-q)z} \right] \\ & \left. + S_G S_G^* \frac{\hbar \omega_G}{16} \left[ b^\dagger b + b b^\dagger \right] \right\} \end{aligned} \quad (\text{B3})$$