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Gravitational Frequency Shifts for Photons and Particles

Jing-Gang Xie

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***Abstract*—**The research, in this case, considers the integration of the Quantum Field Theory and the General Relativity Theory. As two successful models in explaining behaviors of particles, they are incompatible since they work at different masses and scales of energy, with the evidence that regards the description of black holes and universe formation. It is so considering previous efforts in merging the two theories, including the likes of the String Theory, Quantum Gravity models, and others. In a bid to prove an actionable experiment, the paper's approach starts with the derivations of the existing theories at present. It goes on to test the derivations by applying the same initial assumptions, coupled with several deviations. The resulting equations get similar results to those of classical Newton model, quantum mechanics, and general relativity as long as conditions are normal. However, outcomes are different when conditions are extreme, specifically with no breakdowns even for less than Schwarzschild radius, or at Planck length cases. Even so, it proves the possibilities of integrating the two theories.

***Keywords*—**General relativity theory, particles, photons, quantum gravity model, gravitational frequency shift.

I. Introduction

THERE is no doubt about the successfulness of theoretical physics, specifically in providing the gateway to comprehending the physical phenomena. Numerous theories are explaining how things occur in the way they do [1]. Examples include the likes of the Quantum Field Theory (QFT) and the General Relativity Theory (GRT). As renowned models when it comes to understanding behaviors of particles, the two given theories always disagree since they work at entirely different degrees and masses. It means that they are incompatible, evidenced by the case of black holes and universe expansions, among other instances [2]. Physicists have attempted and are still trying to test the compatibility of the QFT and the GRT. For example, take the incident of Quantum Gravity, coupled with that of the String Theory. They represent experiments aimed at integrating the functionalities of the QFT and the GRT. However, there is no universal success so far. That is why this paper proposes an alternative framework for finding the point at which the two theories intersect, thereby giving an actionable approach to the integration of the QFT and the GRT.

II. Background

Reference [3] shows that the QFT represents not only a conceptual but also mathematical framework for conventional particle-based physics studies. In a more informal outlook, the QFT is a derivation of quantum mechanism, denoted as QM. It deals with particles in the context of fields, which signifies systems characterized by infinite quantity regarding degrees of freedom. When taken in a formal scope, the model which typifies metaphysical inferences portrays the world as having a variance with particles' fundamental classical conceptions, including various QM features [4]. On the other hand, the GRT gravitation geometry model was proposed in 1915 by Albert Einstein. The theory simplifies special relativity and the Newtonian principle of general gravitation, thereby predisposing a combined explanation of gravity as a component of space, time or space-time with regards to geometry [4]-[6].

Based on the descriptions above, it is evident that the two theories are fundamental discoveries of all time in physics. Even so, there is the need to acknowledge that, when treated in unison, they are ever presenting challenges [6]. It is because; following the combination of the QFT and the GRT, the introduction of energy "uncertainty" in quantum theory merges with special relativity's mass-energy equivalence, thereby allowing quantum fluctuations to form particle or anti-particle pairs. The outcome is no self-consistent model, which simplifies the general, single-particle Schrödinger equation into a quantum wave equation of relativity [7]. This problem continues to plague those who try to unify the QFT and the GRT.

III. Research Gap

Despite the efforts described above, the remaining fact is that the resulting situation reverses completely in the milieu of the quarks and gluons theory, which encompasses particles that are interacting strongly in the atomic nucleus [8]. This portrayal is that of a theory describing particles that are interacting strongly; namely, quantum chromodynamics (QCD). With these results, it is clear that physics of strong interactions lacks analytical technique up to date [9]. The need to find one is what the following context presents since the existing numerical techniques provide possibilities. These are only significant in prediction-making using first principles and creating the theory's fundamental comprehension.

Jing-Gang Xie is with the Varian Medical Systems, 911 Hansen Way, Palo Alto, CA 94304, USA (e-mail: Jing-Gang.Xie@varian.com, 650-424-6519).

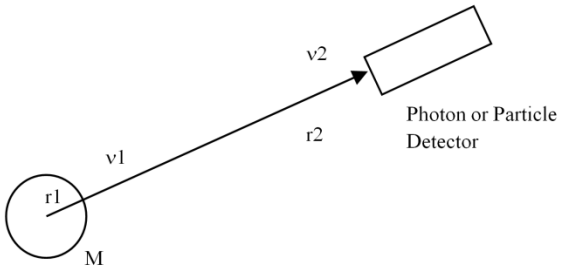


Fig. 1 A photon of ν1 frequency moves away from the object's surface with radius r1 and mass M. The photon detector placed at r2 is inclined to capture the frequency redshift of the photon (z = (ν1/ν2) - 1) because of its loss in momentum via the object's gravitational field

IV. The Approach

In finding the analytical process, this paper checked the derivations of the QFT and the GRT. It did so by applying the same assumptions that are original to the two theories but introduces some deviations. The aim was to get new equations with similar results to those produced by classical Newtonian law, general relativity, and quantum mechanics under normal circumstances. Thus, the starting point involved the determination of the light frequency redshift in regards to the GRT (there was no involvement of photons at that point). It is where $E=h\nu=mC^2$ of Einstein's theory followed the modification of the Newtonian universal gravitation law, as well as the second law of Newton. The frequency shifts obtained were applied to photons and particles, thereby leading to the change of m under the immediate gravitational field. This undertaking predisposed a new mechanism of merging the QFT and the GRT as derived below.

V. The Derivation for Photons

As illustrated in Fig. 1, there is an object with mass (M) and radius (r1). It is uncharged and non-rotating with spherical symmetry. There is the emission of a photon having a basic frequency (ν1) from the object's surface and traveling away from it along the direction of the radius. The assumption is that the momentum of the photon (P = mC) is poised to vary in the object's gravitational field while its velocity remains as a constant (C). From this, there is still the possibility of using Newton's classical law of universal gravitation and the second law of Newton to explain the dynamic changes of the photon momentum even if its rest mass, $m_0 = 0$.

$$-\frac{dP}{dt} = -\frac{d(mC)}{dt} = \frac{GmM}{r^2} \tag{1}$$

where m is the energy equivalent mass of the photon based on $E = h\nu = mC^2$, h represents the Planck constant, G signifies the gravitational constant, and r stands for the distance between the photon and the object's center.

The (-) sign for the change of momentum indicates the reduction of the photon momentum by the gravitational force as it moves away from the central point of a large mass.

From the combination of (1), the mass formula and Einstein's energy

$$-\frac{d(h\nu)}{Cdt} = -\frac{d(h\nu)}{dr} = \frac{Gh\nu M}{C^2r^2} \tag{2}$$

or

$$-\int_{\nu 1}^{\nu 2}\frac{d\nu}{\nu} = \int_{r1}^{r2}\frac{GMdr}{C^2r^2} \tag{3}$$

In finding the solution to (3), the derivation below emerges

$$\nu 2 = \nu 1 \exp[(\tfrac{GM}{C^2})(\tfrac{1}{r2} - \tfrac{1}{r1})] \tag{4}$$

Therefore, the observation is that (4) is usable in calculating the resulting frequency redshift at r2 following the emission of the photon from the object's surface at r1.

VI. Derivations for Particles

Similarly to photons, particles follow derivation steps based on (5):

$$-\frac{dP}{dt} = -\frac{d(mV)}{dt} = -\frac{dm}{dt}V - m\frac{dV}{dt} = \frac{GmM}{r^2} \tag{5}$$

The signs denote the same elements as outlined when deriving the formula about photons. Through computation process, (5) yields:

$$\left[1 - \left(\frac{V2^2}{C^2}\right)\right] = \left[1 - \left(\frac{V1^2}{C^2}\right)\right] exp\left[-\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2} - \frac{1}{r1}\right)\right] \tag{6}$$

$$v_{m2} = v_{m1} exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2} - \frac{1}{r1}\right)\right] \tag{7}$$

where v_m is the frequency associated with the particle of mass m,

$$m = \frac{m0}{\sqrt{(1-\left(\frac{V}{C}\right)^2)}}$$

and,

$$V = V(r) = \frac{dr}{dt}$$

$$m = m(V) = m[V(r)]$$

Thus, (7), as the derivation of particles, is similar to that of photons in (4).

For further insights, the next section continues.

VII. Frequency Redshift Calculations Formula

Starting with:

$$z = \frac{\lambda_{obsv} - \lambda_{emit}}{\lambda_{emit}} \tag{8}$$

As λ represents the wavelength, there is λ_{obsv}, which is the wavelength observed, while λ_{emit} is the wavelength concerning the source of light. Therefore,

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$$z = exp\left[-\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right]-1 \quad (9)$$

where G accounts for the gravitational constant noted earlier.

M signifies the mass of the non-rotating and uncharged object, which is spherically symmetric, C stands for the speed of light, and r1 is the object's radius, and,

$$v = \frac{C}{\lambda}$$

The computation is,

$$\text{For } r2 \gg r1, Z \sim exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r1}\right)\right]-1 = exp\left(\frac{r_S}{2r1}\right)-1 \quad (10)$$

with $r1 \gg r_s/2 = \left(\frac{GM}{C^2}\right)$,

$$Z \sim \left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r1}\right)\right] = \left(\frac{r_S}{2r1}\right) \quad (11)$$

This representation is the formula for calculating the frequency redshift regarding photons or particles. Even so, there is possible integration process of the formula to find the one for relativity redshift.

VIII. Relativity Redshift Formula

Based on (11), there is a theoretical derivation from the Einstein's equations' Schwarzschild solution to get the relativity redshift of (12) as presented below [10].

$$Z = \frac{1}{\sqrt{\left(1-\frac{r_S}{r}\right)}}-1 \quad (12)$$

With the Schwarzschild radius denoted as,

$$r_S = \frac{2GM}{C^2},$$

According to the approximation of the first order for a weak gravitational field (where r is inadequately large as opposed to the Schwarzschild radius r_s), the formula for redshift emerges as,

$$Z \sim \frac{r_S}{2r} = \frac{GM}{C^2 r} \quad (13)$$

By analyzing the entire formula derivation process, it is a fact that (11) is analogous to (13) derived with general relativity based on approximations of weak gravitation. As such, it is conclusive that (11) and (13) are applicable in the accurate calculation of Earth-bound redshifts given by the Solar, the Pound and Rebka experiment, and the Sirius B White Dwarf in Table I [11].

TABLE I
The Experimental Outcome is Similar between General Relativity Formula and Formula of the New Redshift Calculation

	Measurement	General Relativity Formula (12)	(9)
Pound & Rebka Experiment (frequency redshift)	$(2.56+/-0.25)\times10^{-15}$	$(2.46)\times10^{-15}$	$(2.44)\times10^{-15}$
Solar wavelength redshift $M_{sun} \sim 1.99\times10^{8}$ kg $r_{sun} \sim 6.96\times10^{8}$ meters	$(2.12)\times10^{-6}$	$(2.12)\times10^{-6}$	$(2.12)\times10^{-6}$
Sirius B white dwarf wavelength redshift $M_{siriusB} \sim 0.97M_{sun}$ $r_{siriusB} \sim 0.0084r_{sun}$	$(2.44 \sim 3.50)\times10^{-4}$	$(2.47)\times10^{-4}$	$(2.47)\times10^{-4}$

In this case, for r2 >> r1, where M is low, Taylor series expansions can either be (4) or (7) as,

$$v2 = v1\left\{1-\left(\frac{GM}{C^2 r1}\right)+\frac{1}{2}\left[\left(\frac{GM}{C^2 r1}\right)^2\right]-\frac{1}{6}\left[\left(\frac{GM}{C^2 r1}\right)^3\right]+\cdots\right\} \quad (14)$$

By including (14) and the energy-mass formula of Einstein, the result is,

$$m_2C^2 = m_1C^2 - \frac{Gm_1M}{r_1}\left[1-\frac{1}{2}\left(\frac{GM}{C^2 r_1}\right)+\frac{1}{6}\left(\frac{GM}{C^2 r_1}\right)^2-\cdots\right] \quad (15)$$

But, when there is weak gravitational field, where r1 >> r_s/4, the formula is,

$$m_1C^2 \sim m_2C^2 + \frac{Gm_1M}{r_1} \quad (16)$$

Formula (16) is the outcome of energy conservation observed in particles or photons when there is the presence of a weak gravitational field. It means that the particle or photon is inclined to lose some percentage of its mass equivalent energy as a way of compensating for the gravitational potential gain in classical expression of Newton. This happening takes place as the photon moves away from the object with large mass. That explains why the GRT gets a relatable equation as (16), which denotes that r1 = $GM/C^2 = r_s/2$, $m_2C^2 \sim 0$, and redshift $z \sim \infty$. It implies that the photon detector can discover an object with a black hole without light inside the r1 region at an infinite distance. This result resembles that one of general relativity in (12) when r1 = r_s. Nonetheless, (16) will be invalid under conditions of the high gravitational field, specifically where r1 = $GM/C^2 = r_s/2$. So, the $z \sim \infty$ prediction may lack accuracy when the radius of the large mass is close to or less than the Schwarzschild radius r_s. In a nutshell, (15) with approximation terms of a higher order is more befitting in describing the photon energy conservation, while (9) is suitable for the calculation of the redshift in situations of the high gravitational field. Moreover, it is vital to understand that the predictions of (9) are finite or more modest in strong gravitational field scenarios compared to general relativity according to (12), specifically where r1 < ~ $GM/C^2 = r_s/2$. Alternatively, (15) is

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likely to exhibit the presence of attractive forces and expulsive forces as [$\propto$ (-1/r^2, -1/r^4, etc.] and [$\propto$ (+1/r^3, +1/r^5, etc.)], respectively. The combination involving attractive and expulsive forces will exert less action to the dynamic changes of photon momentum or gravitational shift. It is deducible that, when the object assumes a true black hole without light emission from the object, it can reach the detector at a longer distance only when r1 -> 0 << rs/2 = GM/C^2 based on z ~ ∞ of (9).

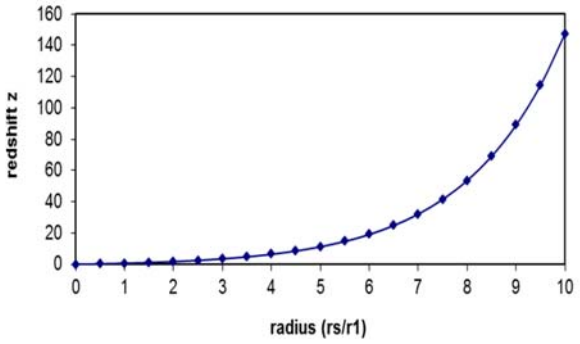


Fig. 2 The calculated gravitational redshift from (9)

Accordingly, Fig. 2 shows the computed gravitational redshift as the rs/r1 function using (9). In an example, when r1 ~ rs/4.8, z of redshift is ~ 10. This experimental result seems to complement the redshift's modest values because the highest redshift becomes 8.27 from distant gamma ray bust of GRB 090423.

IX. Possible Variations

The other variation to consider includes, first, the classical Newton's Law for approximating particles as follows;

From (6) where;

$$\left[-\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right] \ll 1, \text{ and } \left(\frac{V1^2}{C^2}\right) \ll 1$$

$$\left[1-\left(\frac{V2^2}{C^2}\right)\right] \sim \left[1-\left(\frac{V1^2}{C^2}\right)\right]\left(1-\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right)$$

or

$$\left[1-\left(\frac{V2^2}{C^2}\right)\right] \sim \left[1-\left(\frac{V1^2}{C^2}\right)\right]-\left[1-\left(\frac{V1^2}{C^2}\right)\right]\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)$$

$$\left(\frac{V1^2}{C^2}\right)-\left(\frac{V2^2}{C^2}\right) \sim -\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)+\left(\frac{V2^2}{C^2}\right)\left(\frac{2GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)$$

or

$$\frac{1}{2}mV1^2-\frac{1}{2}mV2^2 \sim -GMm\left(\frac{1}{r2}-\frac{1}{r1}\right) \quad (17)$$

The second variation is the one consisting of particle energy in gravitational field as;

$$detE = \det(h\nu) = h(\nu 2-\nu 1) = h\nu 1\left\{exp\left[\left(\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right)\right]-1\right\}$$
$$=\frac{m0}{\sqrt{\left(1-\left(\frac{V1}{C}\right)^2\right)}}C^2\left\{exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right]-1\right\} \quad (18)$$

or

$$detE \sim -\frac{m0}{\sqrt{\left(1-\left(\frac{V1}{C}\right)^2\right)}}\left[GM\left(\frac{1}{r2}-\frac{1}{r1}\right)\right] \quad (19)$$

where, M is low.

X. Proposed Experimental Verification

After deriving the formulas theoretically, it is vital to test their applicability experimentally. This paper proposes the following procedure.

First, the general relativity derived redshift in (12) breaks when r is less than or equal to r_s = 2GM/C^2. Since quantum mechanics is devoid of the gravitational redshift, the new (9) is apt to give the similar results to the ones from general relativity based on approximations of low mass, M. However, it is not going to break even when r is less than or equal to r_s = 2GM/C^2.

Second, it is appropriate to design some experiments aimed at verifying (4, 7, 9) under extreme circumstances, in that, r_s < 2GM/C^2. Table I presents more information on the same.

Third, for the scale of cosmology, it is critical to find the radiation with high redshift coming from black holes that are very dense. Whereby, there should be the checking of mass and distance, independent of each other first. Further, when it comes to very small-scale quantum range, where r2 can approximately be at infinity, $MC^2 = h\nu_M$, r1 ~ λ_M, from (4),

$$\nu 2 = \nu 1 \exp[(\frac{GM}{C^2})(\frac{1}{r2}-\frac{1}{r1})] \sim \nu 1 \exp[-(\frac{GM}{C^2})(\frac{1}{r1})] \sim \nu 1\, exp[-(\frac{Gh}{C^3})(\frac{1}{\lambda_M{}^2})] \quad (20)$$

or $\nu 2 = \sim 0.6\, \nu 1$, at r1 ~ λ_M ~ ℓ_P ~ 1.616x10^{-35} meter, where the Planck length ℓ_P is the scale at which the gravity and space-time from classical physics laws are not valid, and quantum effects dominate.

Finally, to create high M, the focus can be on dense photons in a small volume or increase in the photon's frequency. Otherwise, in the case of particles, there can be an acceleration of their speed to match that of light. In so doing, there is a possibility of detecting energy change from (18) and (19) in any system without necessarily large M.

XI. Further Discussion

After the theoretical derivations followed by experimental elaborations, it is shown that the QFT and GRT can be integrated given certain conditions where aspects favor both theories. Various speculations are derivable from the entire process.

First, if the photon moves towards the large mass' center, there is likelihood the gravitational frequency will undergo sign transformation to form:

$$\nu 2 = \nu 1 exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r1}-\frac{1}{r2}\right)\right]$$

Therefore, the gravitation field can influence the photon frequency to produce the blueshift. Subsequently, the given test

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procedure can be useful at a far distance when observing the mixing difference of the photon frequency between the blueshift photons and the non-shift ones.

Second, any field waves moving at a speed of light (including the gravitational waves) close to a large mass can experience quantization with a unit mass equal to those of photons. Therefore, those waves, for instance gravitational waves, can also attain frequency redshift and or blueshift. It only depends on the waves' direction. This implication is where the proposed experiments can become handy in measuring the frequency shifts from the stated waves at a far distance.

Finally, the frequency shift formula's large mass M can be substituted with strong electromagnetic fields, moving with the speed of light, in the framework of energy-mass (1), (5). Hence, all the discussions above can be used in those fields. For instance, if a photon moves away from or towards an unyielding electromagnetic field (including a light field), it should characterize frequency redshift or blueshift effect. Besides, take the situation of small scale, high mass case; whereby, based on (4) or (7), when r2 >> r1, r1 is minuscule while M is high and $v2$ is significantly different from $v1$ as follows.

$$v2 = v1exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right] \sim v1exp\left[\left(-\frac{GM}{C^2}\right)\left(\frac{1}{r1}\right)\right]$$

XII. Conclusion

QFT and GRT are both accurate in describing the observed universe that we can measure today. However, these two theories work at quite different scales, are incompatible, and do break at extreme conditions. This paper is proposing a new theory, which will start with the original assumptions of the existing theories with some deviations. The basic new assumption is that the photon or particle mass (or their associated frequencies) will change in the gravitational field, as supported by the experimental observation of light frequency redshift and theoretical presentation by GRT. Using Newton's classical law of universal gravitation and the second law of Newton with the new deviated assumption, new frequency shift equation in the gravitational field is obtained,

$$v2 = v1exp\left[\left(\frac{GM}{C^2}\right)\left(\frac{1}{r2}-\frac{1}{r1}\right)\right]$$

The equation is in similar form for both photons and particles. The new equation will get the same redshift result obtained by GRT under weak field condition. Its alternated forms can get the same results as those from classical Newton dynamic equations under low-speed conditions. It integrates QFT and GRT together by applying photon or particle mass equivalent frequencies (through Einstein energy mass $E = hv = mC^2$) to Newton's equations. The new theory shows that at a very strong field, where $r << r_s$ (Schwarzschild radius) or very small space scale at Planck length of ℓ_P, the gravitation field effects to the photons or the particles will get weaker, compared to the breakdowns for both GR and QFT. The results will help to study the black holes and the expansion of the universe.

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