The Generation of Gravitational Wavelets by a Stationary Electromagnetic Wave Closed in a Resonant Cavity

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Abstract

In two earlier studies, we demonstrated that due to the enormous accelerations arising during the perpendicular reflection of a photon by a mirror, the photon's energy distribution behaves as a quadrupole, thereby generating a graviton (or gravitational wavelet) at the same frequency and direction as the reflected photon. For simplicity, only the contribution of the quadrupole component Q_{xx} was previously considered. Here, we extend the analysis to include all quadrupole components associated with perpendicular photon reflection. By applying the standard Einstein quadrupole radiation formula, we show that the energy of the emitted graviton scales as ν^3, revealing a direct coupling between electromagnetism and gravitation. This finding is of high importance because it challenges the long-standing but unverified assumption that graviton energy depends linearly on frequency (ν^1). Our results establish that quantum gravity theories must instead incorporate cubic frequency dependence. Another remarkable feature of the proposed framework is that it offers a theoretical connection between general relativity and quantum approaches, suggesting that confined electromagnetic radiation can serve as a direct source of high-frequency gravitational wavelets.

Keywords: gravitation, general relativity, quantum gravity, gravitational wavelets, Nordström–Einstein paradox, quadrupole radiation, graviton generation, resonant cavity.

1. Introduction

At present, it is assumed that only the most violent events in the Universe, such as neutron stars in spiral evolution or head-on collision, can generate gravitational waves. [1, 2]

In this study, we propose a novel theoretical framework to estimate the gravitational radiation generated by a photon confined within a planar cavity formed by two perfectly reflecting mirrors. In this approach, the photon is represented as an effective point-like mass $m = h \cdot \nu / c^2$, and its center-of-energy motion along the cavity axis is modeled by a smooth resonant trajectory. From the point of view of acceleration, the photon (light wave) reflection is the most violent event in the Universe because the light speed changes from +c to -c in an extremely short period of time $T = 1/\nu$, where ν is the frequency. Starting from the General Theory of Relativity - quadrupole radiation, we demonstrate that this extreme acceleration is responsible for the generation of a significant gravitational power which depends on the frequency to the power of 4 (ν^4). Simultaneously, it is demonstrated that the energy of the radiated graviton E_g, which is emitted in a time $t = T = 1/\nu$, depends on the frequency at the power of 3 (ν^3), which challenges the present hypothesis in quantum gravity theories that this energy would depend on the power of 1 of its frequency ($E'_g=h\nu^1$). The principal conclusions are that the quantum gravity theories should reconsider the present accepted Planck-type equation of energy $E'_g = h\nu$, dependence (not theoretically or experimentally proven), and that reflection of the high frequency/quantity of electromagnetic waves should be researched for experimental equipment to prove that gravitational radiation can be generated in this way.

2. Materials and Methods

The adopted theoretical frame:

The foundation of this work is the General Theory of Relativity. [3]

No post-Einstein theory is used because the GTR is sufficient. On the other hand, the post-Einstein theories cannot be used in this paper because they start from the assumption that the energy of a graviton depends on ν^1, and by now, this hypothesis has not yet been theoretically or experimentally demonstrated.

The photon's energy $E = h\nu$ is represented by its effective mass $m = h\nu/ c^2$ (where h is Planck's constant and ν the photon energy frequency).

The photon motion in the resonance cavity is described by the simple expression:

$$x(t) = (\lambda / 2) \cdot (1 - \cos(\omega t)) \quad (1)$$

where λ is the associated wavelength of the photon, which is equal to the distance between the mirrors, $\omega = \pi / T$, and $T = \lambda / c$.

The considered ansatz offers a smooth classical equivalent of the cavity mode's center of energy that preserves the correct periodicity, spatial nodes, and symmetry of the standing-wave while providing sufficiently regular derivatives (up to third order) required for use in the quadrupole radiation formalism

as formulated in General Relativity. [4]:

$$P_g = (G / 5 c^5) \cdot \langle \Sigma(d^3Q_{ij}/dt^3)^2 \rangle \quad (2)$$

, where Q_{ij} is the quadrupole moment.

Using this model enables a trustworthy estimate of the gravitational radiation produced by the axial oscillating effective mass of a photon.

Method justification for a single photon reflection

Although the quadrupole radiation formula is typically applied to continuous distributions of matter or periodic systems, we extend its use to a singular energy-momentum event - the reflection of a photon - to demonstrate that even such an isolated event can produce gravitational wavelet packets (interpreted as gravitons).

On the other hand, it must be underlined that the reflection of a photon by a mirror generates the maximum possible accelerations in the Universe because the inversion of its speed from c to -c in a very short time (T). So, although the effective mass of a photon is very low, the high value of acceleration during its reflection leads to values of radiated gravitational power that must be taken into account.

Simplifications and conditions

The mirrors are perfectly rigid and reflective, the space-time is flat outside the interaction zone, and reflection occurs in a very short time interval $T = 1/\nu$.

3. Results

Looking at Fig. 1, it can be observed that at t = 0: x (0) = 0 (the photon is on the mirror 1) and at t = T: x (T) = λ (the photon is on the mirror 2). So, in the time T, the photon travels a distance λ. Average speed is $\lambda / T = c$, where $T = \lambda / c = 1 / \nu$. Starting from equation (1),

$x(T) = (\lambda / 2) (1 - \cos (\omega T)) = \lambda$,

$1 - \cos (\omega T) = 2$,

$\cos(\omega T) = -1$.

$\omega T = \pi$, and

$\omega = \pi / T = \pi\nu$ because $T=1/\nu$.

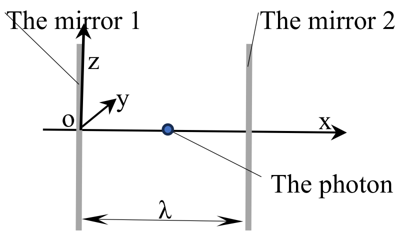

Fig.1-The reflection of a photon between 2 mirrors

Although this ansatz does not represent the literal quantum path of the photon, it captures the essential features of the cavity mode, allowing precise evaluation of the gravitational power radiated per reflection.

The quadrupole expression:

For a point-like effective mass at position r = (x, 0, 0), use the traceless (reduced) quadrupole tensor (Eq.2) leads to:

$Q_{ij} = m \cdot (x_i x_j - (1/3) \delta_{ij} r^2)$

where $r^2 = x^2$, δ_{ij} is the Kronecker delta.

Demonstration steps:

Step 1: Quadrupole components for 1D motion

Position: $r = (x(t), 0, 0)$ so $r^2 = x(t)^2$.

Compute diagonal components from the definition:

$$Q_{xx} = m \cdot (x^2 - (1/3)\, r^2) = m \cdot (x^2 - (1/3)\, x^2) = (2/3)\, m \cdot x^2 \tag{3}$$

$$Q_{yy} = m \cdot (0 - (1/3)\, x^2) = -(1/3)\, m \cdot x^2 \tag{4}$$

$$Q_{zz} = m \cdot (0 - (1/3)\, x^2) = -(1/3)\, m \cdot x^2 \tag{5}$$

Off-diagonal components $Q_{xy} = Q_{xz} = Q_{yz} = 0$ (because $y = z = 0$).

Step 2 -Tracelessness proof

Trace: $Q_{xx} + Q_{yy} + Q_{zz} = (2/3\, m\, x^2) + (-1/3\, m\, x^2) + (-1/3\, m\, x^2) = 0$.

Therefore, Q_{ij} is traceless by construction.

Step 3 - Time derivatives needed in the expression of the gravitational radiation P_g:

Compute d^3/dt^3 of $x^2(t)$:

According to (1),

$x(t) = (\lambda/2)(1 - \cos \omega t)$

Expand $x^2(t)$:

$x^2(t) = (\lambda^2 / 4) \cdot (1 - 2\cdot\cos(\omega t) + \cos^2(\omega t))$

Because $\cos^2(\omega t) = (1 + \cos(2\omega t)) / 2$,

$x^2(t) = (\lambda^2 / 4) \cdot [\, (3/2) - 2\cdot\cos(\omega t) + (1/2)\cdot\cos(2\omega t)\,]$

$= (\lambda^2 / 8) \cdot (3 - 4 \cos \omega t + \cos 2\omega t)$.

The first derivative of x^2:

$d/dt\, (x^2)= (\lambda^2 / 8) \cdot [0 - 4\cdot(-\omega\cdot\sin(\omega t)) + (-2\omega\cdot\sin(2\omega t))] = (\lambda^2 / 8) \cdot [4\omega\cdot\sin(\omega t) - 2\omega\cdot\sin(2\omega t)]$

The second derivative of x^2:

$d^2/dt^2(x^2)=(\lambda^2/8)\cdot[4\omega\cdot(\omega\cdot\cos(\omega t)) - 2\omega\cdot(2\omega\cdot\cos(2\omega t))]$
$= (\lambda^2 / 8) \cdot [4\omega^2\cdot\cos(\omega t) - 4\omega^2\cdot\cos(2\omega t)]$

The third derivative of x^2:

$d^3dt^3(x^2)=(\lambda^2/8)\cdot[4\omega^2\cdot(-\omega\cdot\sin(\omega t)) - 4\omega^2\cdot(-2\omega\cdot\sin(2\omega t))] = (\lambda^2 / 8) \cdot [-4\omega^3\cdot\sin(\omega t) + 8\omega^3\cdot\sin(2\omega t)] = (\lambda^2\ \omega^3 / 2) \cdot (-\sin \omega t + 2 \sin 2\omega t)$.

Square of the third time derivative:

$(d^3/dt^3 (x^2))^2 = (\lambda^2\cdot\omega^3 / 2)^2 \cdot [-\sin(\omega\cdot t) + 2\cdot\sin(2\cdot\omega\cdot t)]^2$

, where we have:

$$(\lambda^2\cdot\omega^3 / 2)^2 = \lambda^4\cdot\omega^6 / 4 \tag{6}$$

$$[-\sin(\omega\cdot t) + 2\cdot\sin(2\cdot\omega\cdot t)]^2 = \sin^2(\omega\cdot t) - 4\cdot\sin(\omega\cdot t)\cdot\sin(2\cdot\omega\cdot t) + 4\cdot\sin^2(2\cdot\omega\cdot t) = f(t) \tag{7}$$

, where f(t) is a notation.

The time average of f(t):

$$\langle f(t)\rangle = (1/T)\int_0^T f(t)\, dt \tag{8}$$

Applying the average equation for each term of f(t), we have:

$$\langle \sin^2(\omega\cdot t)\rangle = 1/2 \tag{9}$$

$$\langle \sin(\omega\cdot t)\cdot\sin(2\cdot\omega\cdot t)\rangle = 0 \tag{10}$$

$$\langle \sin^2(2\cdot\omega\cdot t)\rangle = 1/2 \tag{11}$$

From (7), (8), (9), (10), (11), the value of $\langle f(t)\rangle$ results:

$$\langle f(t)\rangle = 1/2 - 4\cdot 0 + 4\cdot 1/2 = 5/2 \tag{12}$$

From (6) and (12), the average of $(d^3/dt^3 (x^2))^2$ results:

$$\langle (d^3/dt^3 (x^2))^2\rangle = (\lambda^4\cdot\omega^6 / 4)\cdot(5/2) = (5/8)\cdot(\lambda^4\cdot\omega^6) \tag{13}$$

Step 4 - Sum of squared third-derivatives of Q_{ij}

From (3), (4), (5), and (13), the sum of squared third-derivatives results:

$\Sigma(d^3Q_{ij}/dt^3)^2=((2/3)^2+(-1/3)^2+(-1/3)^2)\cdot m^2\cdot (d^3(x^2)/dt^3)^2 =$
$=((4/9)+(1/9)+(1/9))\cdot m^2\cdot(d^3(x^2)/dt^3)^2=(6/9)\cdot m^2(d^3(x^2)/dt^3)^2 = (2/3) \cdot m^2 \cdot (d^3(x^2)/dt^3)^2.$

Step 5 - The time-averaged sum of squared third-derivatives Q_{ij}

$\langle\Sigma(d^3Q_{ij}/dt^3)^2\rangle=(2/3)\cdot m^2\cdot\langle(d^3(x^2)/dt^3)^2\rangle$
$=(2/3)\cdot m^2\cdot(5/8)\cdot\lambda^4\omega^6 = (5/12) \cdot m^2 \cdot \lambda^4 \omega^6.$

Step 6 - Quadrupole power P_g (final symbolic formula)
Insert into Einstein's quadrupole formula:

$P_g = (G / 5 c^5) \cdot \langle \Sigma\{i,j\} (d^3Q_{ij}/dt^3)^2 \rangle$
$= (G / 5 c^5) \cdot (5/12) \cdot m^2 \cdot \lambda^4 \omega^6=(G / c^5) \cdot (1/12) \cdot m^2 \cdot \lambda^4\omega^6.$

Now substitute m and λ, ω in terms of photon frequency ν:

$m = h \cdot \nu / c^2,$
$\lambda = c / \nu,$

$\omega = \pi \cdot \nu.$

Compute $m^2 \cdot \lambda^4 \cdot \omega^6$:

$m^2 \cdot \lambda^4 \cdot \omega^6=(h^2 \nu^2 / c^4) \cdot (c^4 / \nu^4) \cdot (\pi^6 \nu^6) = h^2 \cdot \pi^6 \cdot \nu^4.$

Therefore, the power simplifies to the compact form:

$$P_g = (G \cdot h^2 \cdot \pi^6 / (12 \cdot c^5)) \cdot \nu^4 \quad (14)$$

So, the robust frequency scaling of the radiated gravitational power is $P_g \sim \nu^4$, and the explicit pre-factor is

$$G \cdot h^2 \cdot \pi^6 / (12 \cdot c^5) \quad (15)$$

Due to its definition, this pre-factor can be considered a universal constant.

Step 7-Energy radiated per reflection:
A single reflection (from one mirror) spans time $T = 1 / \nu$ (by model assumption). The energy radiated during one reflection, which is taken as the graviton energy, is:

$$E_g \text{ (per reflection)} = P_g \cdot T = P_g / \nu = [G \cdot h^2 \cdot \pi^6 / (12 \cdot c^5)] \cdot \nu^3 \quad (16)$$

Step 8 - Comparison to a single graviton (quantum) at the photon's frequency

The graviton energy E_g found in this study is a quantum with the same frequency as the photon ($\nu_g \approx \nu$) is extremely small in comparison with the currently used hypothetical value $E'_g = h \cdot \nu$ because of h^2 and c^5, which appear in Eq. 16. This can be considered a major finding because there is no theoretical or experimental evidence to support the equation $E'_g = h \cdot \nu$.

IV. DISCUSSION

The present analysis demonstrates that the reflection of a single photon in a resonant cavity necessarily produces high-frequency gravitational radiation. By representing the photon as an effective oscillating point-like mass, the quadrupole formalism of general relativity could be consistently applied. The resulting expression, $P_g \sim \nu^4$, highlights a robust frequency scaling, while the radiated graviton energy per reflection, $E_g \sim \nu^3$, deviates fundamentally from the widely assumed but unproven relation $E'_g = h\nu$.

The fact that the energy of the radiated graviton must depend on the power of 3 of its frequency was demonstrated with approximation in some other early papers. [5, 6]

This distinction between the graviton energy dependence on ν^3 and ν^1 is critical. It suggests that graviton emission is not simply an electromagnetic analogue but is governed by higher-order couplings between energy, frequency, and space-time curvature. The predicted ν^3 scaling opens a new pathway to connect general relativity with quantum gravity without introducing speculative post-Einsteinian assumptions.

Moreover, equation (14) emphasizes that gravitational effects could become experimentally relevant at high frequencies (hard UV, X-ray), and multilayer reflective surfaces, motivating future efforts to develop high-reflectivity multilayer surfaces working well at these frequencies.

V. CONCLUSIONS

We have shown that photon reflection within a resonant cavity provides a well-defined theoretical mechanism for graviton (or gravitational wavelet) emission. The rigorous quadrupole analysis yields two main results:

(a) - the gravitational radiation power scales as ν^4, and (b) - the graviton energy scales as ν^3, rather than ν^1. This outcome challenges the conventional assumption of linear graviton–frequency dependence and supports the idea that quantum gravity theories should incorporate cubic frequency scaling.

The proposed framework offers a bridge between general relativity and quantum approaches by demonstrating a direct and testable coupling between confined electromagnetic fields and gravitational radiation.

These findings establish a foundation for experimental programs aiming to detect the high-frequency gravitational wavelets generated through high-frequency/energy electromagnetic waves reflection and encourage the reformulation of quantum gravity theories by considering the graviton energy E_g dependence on its frequency at the power of 3 (ν^3).

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