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Do Intergalactic Photons Attract or Repel Each Other?

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Abstract

Through a simple model we study the possibility of photon with mass and charge that can produce an attractive or repulsive force at galactic distances. The main source of the dark mass can be provided by the non vanishing photon mass during the period of radiation of the Universe. A simple analysis shows that the non vanishing photon mass of the order of $m_\gamma \approx 10^{-34}$ eV is consistent with the current observations. This magnitude is less than the most stringent limit on the photon mass available so far, which is of the order of $m_\gamma \approx 10^{-27}$ eV. For distances separating nearby galaxies dominates the force of Newtonian attraction between photonic masses (Dark Matter). For distant galaxies dominates the repulsive electrical force between photon charges (Dark Energy). Also, we review the Red Shift Equation for a photon pair showing that this equation obtained with this simple model can be compared with the result obtained from the generalized special relativity. From the point of view of engineering this approach may be important to to correct distances and times in GPS signals from spacecraft very far from planet Earth.

Index terms: photon mass, gravitation, dark mass, dark energy, photon charge, GPS.

Resumen
(¿Los fotones intergalácticos se atraen o se repelen?)

A través de un modelo simple estudiamos la posibilidad de fotones con masa y carga que pueden producir una fuerza atractiva o repulsiva a distancias galácticas. La fuente principal de la masa oscura puede ser proporcionada por la masa del fotón durante el periodo de radiación del Universo. Un simple análisis muestra que la masa de fotones del orden de $m_\gamma \approx 10^{-34}$ eV es coherente con las observaciones actuales. Esta magnitud es menor que el límite más riguroso de la masa de fotones disponible hasta ahora, que es del orden de $m_\gamma \approx 10^{-27}$ eV. Para las distancias que separan las galaxias cercanas domina la fuerza de atracción newtoniana entre las masas fotónicas (materia oscura). Para galaxias distantes domina la fuerza eléctrica repulsiva entre las cargas de fotones (energía oscura). Además, se revisa la ecuación de desplazamiento del rojo para un par de fotones que muestra que esta ecuación obtenida con este modelo simple se puede comparar con el resultado obtenido de la relatividad especial generalizada. Desde el punto de vista ingenieril, este enfoque puede ser importante para corregir distancias y tiempos en señales de GPS de naves espaciales muy lejos del planeta Tierra.

Palabras clave: masa de fotón, gravitación, masa oscura, energía oscura, carga del fotón.

1. Introduction

The study of gravitational of interaction of Parallel-Propagating Photons has been considered in past by Tolman, Ehrenfest and Podolsky [1], as far as 1931, that first to publish studies on how light interacts with light gravitationally. After that Faraoni and Dumse [2] in 1999 and Jensen in 2013 [3] also addressed this same problem using different approaches. Heeck, [4], was able to derive the first direct bound on the photon lifetime from an analysis of the oldest light that exists in the universe, showing that the half-life of a photon is about 100 million times more than the age of universe. Kouwn *et al*. [5] investigate the cosmology of massive electrodynamics and explore the possibility whether the massive photon could provide an explanation of dark energy. The action is given by the scalar-vector-tensor theory of gravity, which is obtained by nonminimal coupling of the massive Stueckelberg QED with gravity; its cosmological consequences are studied by paying particular attention to the role of photon mass, where the radiation -and matter- dominated epochs are followed by a long period of virtually constant dark energy that closely mimics a ΛCDM model. They also find that the main source of the current acceleration is provided by the nonvanishing photon mass governed by the relation $\Delta \approx m_\gamma^2$. A simple analysis shows that the non vanishing photon mass of the order of $m_\gamma \approx 10^{-34}$ eV is consistent with current observations. This magnitude is far less than the most stringent limit on the photon mass available so far, which is on the order of $\mu \approx 10^{-27}$ eV [6], [7], [8].

Indeed, it has later been realised that neutrino is the lightest particle in the Standard Model (SM) with a mass smaller by at least three orders of magnitude than the electron mass. The 2015 Nobel Prize in Physics was given to the discovery of neutrino oscillations that shows neutrinos are massive. Therefore the SM should have been modified in order to give a natural explanation to the question why neutrino masses are so small but non-zero. A similar modification that makes neutrinos massive may be valid for photon. As dictated by Okun, "such a small photon mass, albeit gauge non-invariant, does not destroy the renormalizability of Quantum Electrodynamics (QED) and its presence would not spoil the agreement between QED and experiment. This also motivates incessant searches for a non vanishing tiny photon mass" [6].

In this short letter, we propose a simple model to explain the possibility of massive photon. In next section Basic theory we give the basic theory and we discuss the photon mass and the charge related with dark matter and energy respectively. The following sections are related with Red Shift Equation due photon pair without theory of general relativity and Red Shift Equation from Generalized Special Relativity Theory, because from the point of view of engineering this approach may be important to correct distances and times in GPS signals from spacecraft very far from planet earth.

2. Basic Theory

We access here the problem of interaction between two particles, via any virtual carrier (graviton or photon), and address afresh the problem of photon inter interaction. Consider two particles with rest masses M and m, exchanging virtual hypothetical carriers of gravity (Gravitons. A spin 2 massless particle - in the framework of quantum field theory), shown in Fig. 1.

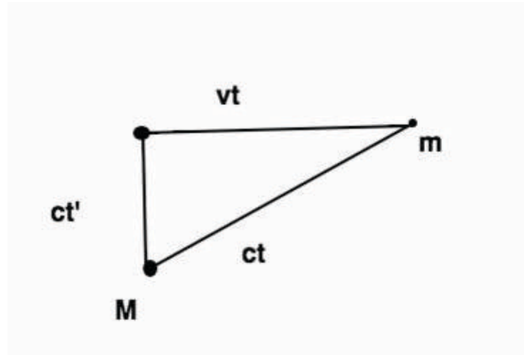

Fig. 1.

This reasoning would be also valid for electrical charges, but in this case the virtual elementary particles would be photons. The particle that emits the virtual photon loses momentum p in the recoil, and the other particle gets the momentum, but not at the time, as we will see, with the caveat of measuring all physical quantities from the reference frame placed at same position as M.

Consider that an inertial reference frame is at the particle M position and that particle m has a velocity v in relation to this frame. Therefore the information (on momentum for instance) triangle leads to the following equation,

$$c^2 t'^2 + v^2 t'^2 = c^2 t^2 \tag{1}$$

The variable t is the time in which the signal that leaves the particle M, at $t = 0$, reaches the original particle m position, that is, at $t = t$, measured at the reference frame at M. Since the particle m has a velocity v, with relation to the reference frame in M, when the information on the position of particle M reaches the original position of m, at $t = t$, the particle m will be at the position $d' = ct'$, where t' is the time when the information that left the particle M reaches the position where m is "now", after a time t has passed, that is, d', $d'^2 = d^2 - v^2t^2$. Based on that, we can construct the above triangle and so, we can write a relation between t and t', where $t - t'$ is the mismatch time between the two information arrivals or momentum exchange.

$$t' = \frac{t}{\sqrt{1 - v^2 / t^2}} \tag{2}$$

Therefore, the gravitational force that m would feel due to M, if $v = 0$, is given by,

$$F^G_{mM}(d) = -GmM / d^2 \tag{3}$$

Of course the force that the particle M feels due to m is given by $F_{nM} = -\, GmM \,/\, d^2$, since it is at rest. Writing now the correct force (calculating the distance at the exact position where the particle m is now) that the mass m feels due to M, we have,

$$F^G_{mM}(d) = -\,GmM \,/\, d'^2 = -\,GmM \,\frac{1}{ct \,/\, \sqrt{1 - v^2/c^2}}$$

$$= -F^G_{mM}(d)\,(1 - v^2/c^2) \qquad (4a)$$

where $d' = d\sqrt{1 - v^2/c^2}$

G is Newton's universal constant of gravitation and d' is the distance of the particle from the central massive photon. As

$$m = m_\gamma = m_0\left(\sqrt{1 - v^2/c^2}\right)^{-1}$$

then, $$F^G_{mM}(d') = -F^G_{m_0M}(d)\sqrt{1 - v^2/c^2} \qquad (4b)$$

Therefore, if $v = 0$, we get the usual $F^G_{mM} = F^G_{mM}$, with the caveat of considering the reference frame glued in M. Equation (4) is our main result.

If we consider photons, of course $v = c$ and the particle rest mass m ($m = 0$) will not feel any force from M ($M = 0$), and viceversa. This happen irrespective to the choice of positioning of the reference frame, since in any case $v = c$.

For photons, the information triangle is equilateral, and that is the reason why photons see each other as static, since the distance between them is $d = ct$. Each side of this information exchange equilateral triangle is d.

If we look the problem from the reference frame glued in m, we conclude that we get the same mismatch calculating the force, and then looking the space-time structure of the problem we have that Proca equations describe the behavior of a massive spin-1 field, and have since been used to set an impressive upper limit on the photon mass of $\mu < 2 \times 10^{-54}$ kg [4], or 10^{-18} eV in the natural units used in this Letter ($h = c = k_B = 1$). However in this case we adopt a lower limit for the mass of the photon in order to have a good match with the actual background radiation of the universe. It would be impossible to perform any experiment which establishes the exact vanishing of the photon mass, but the ultimate upper limit on the photon rest mass, m, can be estimated by using the uncertainty principle to be $m_\gamma \approx h/(\Delta t)c^2 = 10^{-34}$ eV for the current age of the Universe. This simple analysis verifies the deeper study of [5], [6], [7], which using the long-lived low-energy photons of the cosmic microwave background. J. Heeck [5] was able to derive the first direct bound on the photon lifetime from an analysis of the oldest light that exists in the universe. Using the largest allowed value for the photon mass from other experiments, he finds a lower limit of about 3 yr on the photon rest-frame lifetime. After including the relativistic effects of time dilation, this implies that the half-life of a photon of visible light would rise, in the reference system of a resting observer, to about 10^8 years: 100 million times more than the age of universe. This excessive gap means that, for all intents and purposes, the photon lives forever. For photons in the visible spectrum, in all cases CMB spectral distribution for mass is $\mu < 10^{-7}$ eV has no visible effect.

The Heeck's analysis is completely independent of the possible particles in which a photon could disintegrate. It is based on the fact that, if a fraction of the photons in the microwave background had disintegrated, the spectrum of that radiation would not coincide with that of a blackbody. Since the spectrum of the microwave background has been measured with great precision, it possible deviation is strongly constrained by observations.

On the other hand, if photons have mass, the Yukawa force law between two electric charges q_γ and Q_γ separated by a distance d' is

$$F^E_{mM} = k\, q_\gamma\, Q_\gamma \,/\, (d'^2) e^{-\mu d'} (1 + \mu d') \qquad (5)$$

where $\mu = m_\gamma c / h$ includes the photon mass m_γ, the speed of light c, and Planck's constant h. This equation corresponds exactly to the ordinary Coulomb force law $F^E_{mM} = k\, q_\gamma\, Q_\gamma / d'^2$ when the photon mass is zero. However, even for small photon mass, these equations will nearly be the same, since a small factor of μ in the Yukawa force law will hardly make any difference experimentally. On the other hand, a large mass will impose a sharp cutoff in the strength of the force, since the exponentially decaying term in the equation will throttle it. That's how the Yukawa force (with the appropriate changes to represent nuclear forces instead of electromagnetic) predicts the short range of the nuclear force and the value of the pion mass. However for cosmological distances the photon mass may be important as a positive gravitational force separating the galaxies (see equation (4a)).

If $v/c < 1$, but v very close to c we have an attractive force between nearby galaxies given by equation (4b), which can represent the dark matter. If $v/c \geq 1$, we have a repulsive force produced by the dark energy. The main source of the dark energy is provided by the nonvanishing photon mass during the period of radiation of the Universe. If the size of Universe is about $R = 10^{26}$ m, then in electronvolts corresponds to 10^{-34} eV, so this simple analysis shows that the non vanishing photon mass of the order of $m_\gamma \approx 10^{-34}$ eV is consistent with the current observations. This magnitude is far less than the most stringent limit on the photon mass available so far, which is of $m_\gamma \approx 10^{-27}$ eV the order of [8], [9], [11], [12]. In other words, if the photon's mass is 10 million times smaller than that limit, the way that photons interact with the different fields and forces in the Universe leads to a repulsive effect that looks to calling dark energy. In other words, massive photons could cause dark energy.

Here we need to obtain an upper limit on the photon electric charge from the cosmic microwave background. Following [13] and [14], we consider the cosmic microwave background radiation like a black body temperature $T_B = 2.74$ K and the photon number density given by $n_\gamma \approx \beta\,(K_B T_B/hc)^3$ where K_B is the Boltzmann constant, β is a numerical coefficient of order unity. If each photon has a charge q_γ , then the electric force density is proportional to $(n_\gamma\, q_\gamma)^2$ with the condition of

$$(n_\gamma\, q_\gamma)^2 = G\rho^2 \tag{6}$$

where ρ is the average mass density of the Universe. From here we can obtain that $q_\gamma < 10^{-27} e$ in esu units, where e is the electron charge. Then the repulsive force

$$F^E_{mM} = k\, q_\gamma\, Q_\gamma \,/\, (d'^2) \tag{7}$$

would be responsible for the dark energy that separates increasingly distant galaxies. Here we consider the situation where the electric field is parallel to the magnetic field and the vector Poyntig is zero [15]. In short, for distances separating nearby galaxies dominates the force of Newtonian attraction between photonic masses (Dark Matter). For distant galaxies dominates the repulsive electrical force between photon charges (Dark Energy).

From the point of view of engineering this approach may be important to to correct distances and times in GPS signals from spacecraft very far from planet earth. The two last sections are related with this topic.

3. Red Shift Equation due photon pair without theory of general relativity

Conservation of energy yields the fact that the sum of the kinetic and potential energies is a constant. If a photon of mass m is moving under the influence of a gravitational field generated by a massive central body of mass M (massive photon), Newton's law of gravitation shows that the potential energy is given by GMm/d', where G is Newton's universal constant of gravitation and r is the distance of the particle from the central massive body.

If the mass-energy relation $E = mc^2 = h\nu$, which relates the kinetic energy to the product of mass and the square of the speed of light, is introduced, then an 'effective mass' for the photon may be deduced and is given by $m = h\nu/c^2$. The equation expressing conservation of energy then becomes

$$h\nu - GMm \,/\, d' = h\nu - GMh\nu \,/\, d'c^2 = \text{constant}$$

This equation immediately allows the well established expression for the gravitational red-shift to be deduced. From equation (4, or 4'), we have $F^G_{nM} = -\nabla E$, so for a photon with mass, the equation of conservation of energy becomes

$$h\nu - GMh\nu \,/\, d'\, c^2 = h\nu_{r=\infty}$$

$$(\nu_{r=\infty} - \nu) \,/\, \nu = -\,GM \,/\, d'c^2 \tag{8}$$

which is the desired result obtained from the Einstein Theory [9], [10]. In the above derivation of the expression for the gravitational red-shift, no appeal has been made to any aspect of the theory of general relativity, not even the principle of equivalence It seems surprising that the above deduction of an 'effective mass' for the photon allows this simple derivation of the red-shift formula. Although two photons with mass would produce a very small value of red-shift, to compare with equation (8), it is important to obtain the Gravitational Red-Shift using the Generalized Special Relativity theory, (GSR).

4. Derivation of the Red Shift Equation from Generalized Special Relativity Theory

In all basic studies involved in the theory of general relativity, attention was drawn to the three main problems related to it, those are well-known advance of the perihelion of the planet Mercury, the Gravitational Deflection of Light Rays and the Gravitational Red-Shift of Spectral Lines. The gravitational red-shift discussed within the emitted rays from a particle that located in the field of another rest particle due to a spherical symmetry (such as Solar field), the atoms that compose the gases edges of a rest star forms light sources in the star field, and according to this information the Gravitational Red-Shift obtained [3]. This study introduces a new method to obtain the same result of the Gravitational Red-Shift using the Generalized Special Relativity theory, (GSR) by adopting the approximation of the gravitational potential.

The Generalized Special Relativity Theory is a new form of the special relativity theory that adopts the gravitational potential, and it gives the formula of relative mass to be as follows [4]: with our approach the photon mass is

$$m = g_{00}\, m_0 \,/\, \sqrt{g_{gg} - v^2 / c^2} \tag{9}$$

where, $g_{00} = 1 + 2\varphi / c^2$ φ and denotes the gravitational potential, or the field in which the mass is measured. here, we generalize γ to include the effect of gravitation by adopting the weak field approximation where [6]:

$$g_{11} = -1, \ g_{00} = 1 + 2\varphi / c^2 \tag{10}$$

and can be generalized to recognize the effect of motion as well as gravity on time, to get:

$$dt = dt_0 / \sqrt{g_{gg} - v^2 / c^2} \tag{11}$$

Einstein's mass and energy equivalent relation, agrees that the energy of a particle is given by [7]:

$$E = mc^2 = hv \tag{12}$$

where h is Planck's constant and c is the speed of light, substitute the mass m from this one gets:

$$E = mc^2 = m_0 c^2 (1 + \varphi / c^2) \tag{13}$$

The difference in particles or light energy presented as [7], [8], [9].

$$\Delta E = mc^2 - m_0 c^2 = m_0 c^2 (1 + \varphi / c^2) - m_0 c^2 = m_0 \varphi \tag{14}$$

Then $\Delta E / E_0 = \Delta hv / hv_0 = MG / dc^2$. As mentioned before, φ denotes the potential field, which can be given by $\varphi = -Mg/r$ so

$$\Delta E / E_0 = \Delta hv / hv_0 = MG / dc^2 \tag{15}$$

which is equation (8).

So adopting of the weak field approximation in the generalized special relativity, leads to succeed in proving an important theory in physics such as the gravitational red-shift of the spectral lines, and on the other hand, it explains that the appearance of the weak field does not affect the red shift negatively, but, oppositely the generalized special relativity succeeded again.

From the point of view of engineering this approach may be important to to correct distances and times in GPS signals from spacecraft very far from planet earth.

If we have a rocket the principle of equivalence, leads to the prediction of a gravitational frequency shift. A rocket with acceleration g upwards contains a transmitter and a receiver at height L above the transmitter. We view this accelerating rocket from a reference frame which is inertial. At the instant the rocket starts up, the signal is transmitted. The time required to reach the receiver is essentially. But during the propagation of the signal to the receiver, the receiver picks up a velocity

$$v = gt = gL / c \tag{16}$$

Then when the signal is detected the frequency must be the same as that detected by a receiver moving at constant velocity, at the location of the receiver, but not accelerating. To this receiver, the transmitter is a receding source and the frequency will be Doppler shifted downwards:

$$\Delta hv / hv_0 = -v/c = -gL / c^2 \tag{17}$$

By the principle of equivalence, the physics in the accelerating rocket is the same as it would be in a gravitational field of strength. Thus the accelerated observer would attribute the frequency change to the gravitational field, and then the product gL may be identified in terms of the change in gravitational potential, $\Delta\Phi = gL$

$$\Delta v / v_0 = -\Delta\Phi / c^2 \tag{18}$$

As the rocket continues to accelerate with constant velocity, (as long as the velocity does not get too large), the frequency shift will remain constant so that to the observer in the rocket, the frequency of the clock that is driving the transmitter, and that in this case is lower down in the gravitational field, is beating more slowly. So comparing two clocks at different potentials, they should beat at different rates. The rate difference between a clock at potential $\Phi + \Delta\Phi$ and one at Φ can be computed in terms of a fractional frequency shift by reversing the sign in Eq. (18) which is equation (8).

Gravitational frequency shifts in the GPS is as follow. Consider then two clocks, a reference clock at rest on the earth's equator at radius R_E, and an atomic clock in orbit at radius d'. The gravitational potential of the clock in orbit is, to sufficient accuracy

$$\Phi = GM_E / d', \ d' = \sqrt{d^2 - v^2 t^2}$$

where for earth,

$$GM_E = 3.98604415 \times 10^{14} \, m^3/\mathrm{s}^2$$

The total gravitational frequency shift of GPS satellite clocks is therefore

$$\Delta v / v_0 = -GM_E / 'd'c^2 + GM_E / R_E c^2 = 5288 \times 10^{-14}$$

This is actually a huge effect. If not accounted for, in one day it could build up to a timing error that would translate into a navigational error of 13.7 km. Good GPS satellite clocks have intrinsic stabilities that allow them to keep time to within a few parts in 10^{14} after a day. The gravitational frequency shift is thousands of times bigger than this because the distance d' must be corrected according equation $d' = d\sqrt{1 - v^2 / c^2}$.

5. Conclusion

Through a simple model we study the possibility of photon with mass that can produce an attractive or repulsive force at galactic distances. The main source of the dark energy can be provided by the non vanishing photon mass during the period of radiation without Poynting vector of the Universe. A simple analysis shows that the non vanishing photon mass of the order of $m_\gamma \approx 10^{-34}$ eV is consistent with the current observations. It would be certainly impossible to perform any experiment which establishes the exact vanishing of the photon mass, but the ultimate upper limit on the photon rest mass m, can be estimated by using the uncertainty principle to be $m_\gamma \approx h / (\Delta t)c^2 = 10^{-34}$ eV for the current age of the Universe. This magnitude is far less than the most stringent limit on the photon mass available so far, which is of the order of $m_\gamma \approx 10^{-27}$ eV. From the electric point of view, the repulsive force $F_{nM} = kq_\gamma Q_\gamma / d'^2$ would be responsible for the dark energy that separates increasingly distant galaxies, that is, for distances separating nearby galaxies dominates the force of Newtonian attraction between photonic masses (Dark Matter). For distant galaxies dominates the repulsive electrical force between photon charges (Dark Energy).

With this theory, we review the Red Shift Equation for a photon pair showing that equation (8) is obtained with this simple model and compared with the result obtained the generalized special relativity. Also, we review the Red Shift Equation from Generalized Special Relativity Theory, equation (15). From the point of view of engineering this approach may be important to to correct distances and times in GPS signals from spacecraft very far from planet earth.

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