Cosmological Redshift: Experimental Detection of Gravitational Radiation

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In this paper it is shown that according to our new Theory of Gravitation published recently (Howusu 1991) a photon moving in a non-uniform gravitational field radiates energy in the form of gravitational waves thus providing (i) a new pure gravitational resolution of the cosmological redshift and (ii) a theoretical proof that the cosmological redshift is precisely an experimental detection of gravitational radiation and hence waves.

Introduction

Between the years 1910 and 1922 M.V. Slipher discovered the phenomenon of cosmological redshift according to which the spectral lines of the light from distant galaxies are shifted towards the red end of the electromagnetic spectrum. In 1929 E. Hubble published (Hubble 1929) his result of a "roughly linear relation between the velocities and distances" of the galaxies. Then began the search for the theoretical resolution of this extraordinary phenomenon.

One of the earliest theories for the cosmological redshift was due to A. Einstein. According to Einstein the cosmological redshift is a manifestation of the relativistic Doppler effect. Therefore Einstein concluded that there is a mutual recession between every two cosmological units of the universe. And he adopted the Robertson-Walker solution of his gravitational field equations and hence the big bang cosmological models, as is well known.

Next, in the year 1929 (the same year in which Hubble published his law of the cosmological redshift) F. Zwicky (1929) proposed his alternative theory, according to which the cosmological redshift is "a sort of gravitational analog of the well known Compton effect."

In the year 1930 H. Weyl, a great authority on Einstein's theories of relativity wrote the following words concerning the cosmological redshift (Weyl 1930):

> *It is not my opinion that we can vouch for the correctness of the geometrical explanation which relativistic cosmology offers for this strange phenomenon (i.e. redshifts) with any amount of certainty at this time. Perhaps it will have to be interpreted in a more physical manner, in correspondence with the ideas of Zwicky.*

In the year 1935 E.A. Milne (1935) also proposed his alternative theory of the cosmological redshift phenomenon. That same year E. Hubble (the discoverer of the linear law of the cosmological redshift) and R.C. Tolman, (one of the great authorities on Einstein's theories of relativity) wrote the following words concerning the cosmological redshift (Hubble and Tolman 1935):

> *The most obvious explanation of this finding is to regard it as directly correlated with a recessional motion of nebulae, and this assumption has been adopted in the extensive treatments of nebular motion that have been made with the help of the relativistic theory of gravitation and also in the more purely kinematic treatment proposed by Milne. Nevertheless, the possibility that the redshift may be due to some other cause, connected with the long time or distance involved in the passage of light from nebula to observer, should not be prematurely neglected, and several investigators have indeed suggested such other causes, although without as yet giving an entirely satisfactory detailed account of their mechanism. Until further evidence is available, both the present authors wish to express an open mind with respect to the ultimately most satisfactory explanation of the nebular redshifts and, in presentations of purely observational findings, to continue to use the phrase "apparent" velocity of recession. They both incline to the opinion, however, that if the redshift is not due to recessional motion, its explanation will probably involve some quite new physical principles.*

Since Milne several others have also seen the need to construct alternative theories for the cosmological redshift (Rudnicki 1991, Napier 1991, Arp 1991, Clube 1991, Ghosh 1991, Marmet 1991, Jaakkola 1991, Kropotkin 1991, Dart 1993).

Now in a recent paper, "On the Gravitation of Moving Bodies" (Howusu 1991) we published our new Theory of Gravitation which may be summarized as follows:

Definition

If in an inertial reference frame an entity of non-zero rest mass m_o moves with an instantaneous linear velocity $\mathbf{u}$ *then it possesses an instantaneous mass m given by*

$$m = \left(1 - \frac{u^2}{c^2}\right)^{-\frac{1}{2}} m_o$$

where c is the speed of light in vacuo.

Definition

If in an inertial reference frame a photon moves with an instantaneous frequency ν then it possesses an instantaneous mass m given by

$$m = \frac{hn}{c^2}$$

where h is Planck's constant and c is the speed of light in vacuo.

Definition

If in an inertial reference frame an entity of instantaneous mass m moves with an instantaneous linear velocity $\mathbf{u}$ *then it possesses an instantaneous linear momentum* $\mathbf{P}$ *given by*

$$\mathbf{P} = m\mathbf{u}$$

Law of Motion

In all inertial reference frames the instantaneous time rate of change of the instantaneous linear momentum $\boldsymbol{P}$ *of an entity is equal to the total instantaneous external gravitational force* $\mathbf{F}_g$ *acting on it,*

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{P} = \mathbf{F}_g$$

Law of Gravitation

In all inertial reference frames an entity having an instantaneous mass m at the instantaneous position $(\boldsymbol{r},t)$ *in vacuum space-time is attracted by an entity having an instantaneous mass* m' *at the instantaneous position* $(\mathbf{r}',t')$ *in vacuum space-time with a retarded gravitational force* $\mathbf{F}_g$ *which is directly proportional to m and* m' *and inversely proportional to the square of their separation,*

$$\mathbf{F}_g(\mathbf{r},t) = -G\frac{m(\mathbf{r},t)m'(\mathbf{r}',t')}{|\mathbf{r}-\mathbf{r}'|}$$

and

$$t - t' = \frac{|\mathbf{r}-\mathbf{r}'|}{c_g}$$

where G is the universal gravitational constant and c_g *is the speed of the gravitational effect in vacuo.*

In the original paper (Howusu 1991) it was shown how our new Theory of Gravitation resolves the classic problems of (i) anomalous orbital precession in the solar system, (ii) gravitational deflection of star light in the solar system and (iii) gravitational redshift of the frequency of star light in the solar system, in perfect agreement with experiment (and Einstein's Theory of General Relativity). It was also shown that according to our new Theory of Gravitation every linearly accelerating entity of non-zero rest mass radiates energy in the form of gravitational waves, provided the speed of the gravitational effect *in vacuo* c_g (which has yet to be determined experimentally) is finite.

Next, in the paper, "General Mechanics of a Photon in the Gravitational Field of a Stationary Homogeneous Spherical Body" (Howusu 1993), it was shown how, according to our new Theory of Gravitation, a photon is accelerated linearly in the gravitational fields of massive bodies, thus predicting black holes, in perfect agreement with Einstein's Theory of General Relativity. (It may be noted that the said linear acceleration of a photon in a non-uniform gravitational field is similar to the acceleration it will experience in a non-uniform glass medium whose refractive index increases continuously from unity. Thus the speed of the photon never exceeds c, the value *in vacuo*.)

Now in this paper, we shall show how, according to our new Theory of Gravitation, a photon accelerating in a non-uniform gravitational field, as stated above, radiates energy in the form of gravitational waves which in turn propagate unattenuated *in vacuo*.

Gravitational Radiation of a Photon in a Non-Uniform Gravitational Field

Consider a photon moving in a gravitational field having scalar potential Φ'_g (such as the gravitational field exterior to a galaxy). Then, precisely as an entity of non-zero rest mass, the photon has an instantaneous free space non-potential energy given by

$$E_{np} = mc^2 = h\nu \tag{1}$$

as is well known experimentally. Also, precisely as an entity of non non-zero rest mass, the photon has an instantaneous gravitational potential energy given by

$$E_p = m\Phi'_g = \frac{h\nu}{c^2}\Phi'_g \tag{2}$$

according to our law of gravitation. Thus the total energy of the photon in the gravitational field is given by

$$E = h\nu\left(1+\frac{1}{c^2}\Phi'_g\right) \tag{3}$$

Now since the gravitational field is conservative it follows that the total energy of the photon is conserved, precisely as the corresponding total energy of an entity of non-zero rest mass. Thus the instantaneous frequency of the photon is given by

$$\nu(\mathbf{r}',t') = \left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}'_o,t'_o)\right]\left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}',t')\right]^{-1}\nu(\mathbf{r}'_o,t'_o) \tag{4}$$

where $(\mathbf{r}'_o,t'_o)$ is any particular point in space-time along the trajectory, such as the point of emission. (It may be noted that (4) is in fact the gravitational frequency shift relation for the photon according to our new Theory of Gravitation, and it is in perfect agreement with experiment as well as Einstein's Theory of General Relativity.) It therefore follows from definition above that the instantaneous mass m of the photon in the gravitational field is given by

$$m(\mathbf{r}',t') = \frac{h}{c^2}\left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}'_o,t'_o)\right]\left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}',t')\right]^{-1}\nu(\mathbf{r}'_o,t'_o) \tag{5}$$

Consequently, by our Law of Gravitation above, the instantaneous scalar potential Φ_g created by the photon at the point $(\mathbf{r},t)$ in vacuum space-time is given, precisely as in Newtonian Theory of Universal Gravitation, by

$$\Phi_g(\mathbf{r},t) = -\frac{Gm(\mathbf{r}',t')}{|\mathbf{r}-\mathbf{r}'|} = \frac{D_o\left[1+\left(1/c^2\right)\Phi'_g(\mathbf{r}',t')\right]^{-1}}{|\mathbf{r}-\mathbf{r}'|} \tag{6}$$

where

$$D_o = -\frac{Gh}{c^2}\left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}'_o,t'_o)\right]\nu(\mathbf{r}'_o,t'_o) \tag{7}$$

and

$$t' = t-\frac{|\mathbf{r}-\mathbf{r}'|}{c_g} \tag{8}$$

Thus it follows from (6) and (8) and some manipulation (preferably in Cartesian Coordinates) that

$$\nabla^2\Phi_g(\mathbf{r},t)-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\Phi_g(\mathbf{r},t) = -4\pi D_o\left[1+\frac{1}{c^2}\Phi'_g(\mathbf{r}',t')\right]^{-1}\delta(\mathbf{r}-\mathbf{r}') \tag{9}$$

which is a wave equation corresponding to the radiation of energy by the photon in the form of gravitational waves and their propagation *in vacuo*, provided the function is continuous and twice differentiable with respect to time. And this condition is guaranteed for every non-uniform gravitational field, since the photon accelerates linearly in it.

Application to Cosmological Redshift

Consider a photon moving in the gravitational field exterior to a homogeneous spherical body of radius R and rest mass M_o (such as a galaxy). Then, as is well known or may be shown from our new Law of gravitation above,

$$\Phi'_g(\mathbf{r}',t') = -\frac{GM_o}{r'}, \quad r' \geq R \tag{10}$$

Also its instantaneous radial speed is given by (Howusu 1993)

$$r'^2 = \left[1-\frac{k_o}{c^2r'}\right]\left[1+\frac{k_o}{c^2r'}-\frac{l^2}{c^2r'^2}+\frac{k_ol^2}{c^2r'^3}\right]c^2 \tag{11}$$

which implicitly defines the function

$$r' = r'(t') \tag{12}$$

and hence the function

$$r' = r'(\mathbf{r},t) \tag{l3}$$

by virtue of (9). Moreover, since this gravitational field is non-uniform, it satisfies the conditions of continuity and differentiability *a fortiori*. Consequently, it follows from the above that the photon radiates energy in the form of gravitational waves which propagate *in vacuo*.

It may be noted that the photon radiates energy in the form of gravitational waves both when it is approaching (decelerating) or receding (accelerating) from the body.

Hence, a photon moving in the gravitational field of a galaxy will loose energy continuously in the form of gravitational radiation. Consequently, a photon emitted from a distant galaxy will loose energy continuously in the form of gravitational radiation as it traverses the gravitational fields of all the intervening galaxies on its way to the earth, in which case it will undergo a redshift of frequency. In this way, therefore, our new Theory of Gravitation may provide an entirely new resolution of the phenomenon of the cosmological redshift.

Evidently, our new resolution of the phenomenon of cosmological redshift in this paper is purely gravitational. Herein lies one of its great appeals. Moreover, the cosmological redshift predicted by our new Theory of Gravitation will have some direct variation with the distance of the source of the photon. And it is obvious that a linear variation will only be a first approximation, precisely as is shown experimentally since 1929.

Conclusion

In this paper it is shown that according to our new Theory of Gravitation (Howusu 1991) a photon moving in a non-uniform gravitational field continuously radiates energy in the form of gravitational waves. This provides a possible purely gravitational resolution of the famous phenomenon of cosmological redshift.

It may be noted that with a purely gravitational resolution of the cosmological redshift, the universe need not be expanding and there need not be a big bang in our new Theory of Gravitation, as in some previous theories of gravitation.

Furthermore, the constant D_o in the expression for our gravitational scalar wave potential of the photon (6) and (9) contains the most interesting factor,

$$\frac{Gh}{c^2} = Ghe_o m_o = 4.912 \times 10^{-61}\ \mathrm{m^3 s^{-1}}$$

which is the product of the four fundamental constants of nature namely, the universal gravitational constant G, Planck's constant h, the permittivity of empty space e_o and the permeability of empty space m_o. This may be evidence for a hitherto unsuspected coupling of at least the electromagnetic and gravitational fields—the two long range interactions of nature. And this coupling is such that a photon (the carrier of the electromagnetic interaction) may emit gravitons (the carriers of the gravitational interaction) over several billions of light years.

The first profound consequence is that if one photon may emit gravitational radiation continuously over several billions of light years as shown in this paper then it is natural to suspect that one photon contains several billions or trillions or more gravitons. Thus the graviton is a more fundamental entity of nature than the photon. And in fact, the electromagnetic interaction (photon) may be composed of and hence derivable from the gravitational interaction (gravitons). Herein may lie a new clue to the ultimate unification of the two long range interactions in nature.

The second profound consequence of this paper is that if one photon may have to emit several billions or trillions or more gravitons continuously over several billions of light years as shown in this paper for its frequency to shift as observed experimentally in the cosmological redshift phenomenon, then we have an indication of the relatively small geometrical sizes of gravitons in comparison with the geometrical sizes of photons.

Moreover, we also have an indication of the relatively small size of the quantum of energy for gravitons in comparison with the quantum of energy for photons. This may be seen from the numerical value of the constant Gh/c^2 that occurs in the amplitude of our gravitational waves in this paper. In this relatively small size of the quantum of energy for gravitons may lie the ultimate explanation of their non-detection in the form of gravitational waves on the laboratory scale so far. For it is only the actions of gravitons on objects of comparable geometrical size or quantum of energy that may be significant enough to be measurable over laboratory distances and times. The proof of this point is that according to this paper even a photon emitting gravitons continuously requires cosmological distances and times to manifest significant and measurable changes in its energy—the cosmological redshift.

The final profound consequence of this paper is that the very phenomenon of the cosmological redshift is precisely an experimental observation of the manifestation of gravitational radiation and waves (gravitons) on the cosmological scale. And this is equivalent to an experimental detection of gravitational waves and hence gravitons. Most importantly, our gravitational wave given by (9) and hence the total gravitational energy radiated by the photon between its points of emission and reception, contain explicitly the speed of the gravitational wave *in vacuo*, c_g. This may provide a clue to the first determination of the speed of the gravitational effect *in vacuo*.

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