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The Speed of Light and the Principle of Energy Conservation

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Abstract

Adopting *a priori* the Principle of energy conservation, we found that the speed of light emitted (in the cosmological past) by nearby or distant galaxies with the cosmological redshift z_G is lower by the factor $(1 + z_G)$ than the (current) speed of this light c ($\approx 3\times10^8$ m sec^{-1}) reaching the Earth. We have also suggested that the radius of the Hubble sphere in the past was smaller by the same factor. We find that the light speed increased by nearly 2 cm sec^{-1} y^{-1} for about the last 12 Gy.

Keywords: Principle of energy conservation, speed of light, nearby galaxy, distant galaxy, cosmological past, Hubble sphere

Introduction

Until recently, numerous scientists proposed their varying speed of light theories. Excellent reviews of these theories are presented by Magueijo [1] and Farrell and Dunning-Davies [2]. All of these scientists suggest that the speed of light continuously decreased to its current speed c over the lifetime of the Universe. In this communication, we will consider the possibility that the speed of light of nearby or distant galaxies[1] increased to its present speed c through the cosmological history of the Universe. Premović entertains this possibility in communication [4] as an explanation of the redshift of the Lyα emissions sourced by the distant galaxy EGSY8p7.

According to the standard cosmology, nearby and distant galaxies recede from the Earth because the Universe is expanding at a constant rate or better because of the space expansion. The distance between a nearby or distant galaxy and the Earth is related to their "cosmological redshift" z_G (> 0). The larger this distance, the higher the measured cosmological redshift. This shift at present tis defined by the following equation

$$z_G = (\lambda - \lambda_G)/\lambda_G \quad \dots (1)$$

[1] We define nearby galaxies as those whose redshift z_G is from 0.001 to 0.1 (or $0.001 \le z_G \le 0.1$) and distant and galaxies with $z_G > 0.1$ [3]. Of course, there is no sharp line between nearby and distant galaxies.

where λ_G is the wavelength of monochromatic light (or the stream of monoenergetic photons) (hereinafter light) emitted by a nearby or distant galaxy in the cosmological past and λ is the wavelength of this light measured by an Earth's observer at present.

The energy loss of the wavelength of redshifted light is a major concern for cosmologists. Indeed, when this light moves from a nearby or distant galaxy to the Earth its energy appears to decrease. This violates the Principle of energy conservation. This issue has been of interest to many cosmologists but consideration of their approaches and solutions is beyond the scope of this work.

Discussion and Derivations

Modern cosmology claims that the universe over 12.8 billion years ago (or 1 billion years after the Big Bang) was similar to today's Universe. In addition, after billions of years in the future, the Universe will be similar to its "primordial" (modern) Universe. The law of energy conservation is one of the most important laws of physics and has not been violated in any known physical process in our Universe. Hence, it is reasonable to assume that this law was not violated in the Universe from 12.8 billion years ago to the present day. Nor will it be violated in some distant future of the Universe. This communication adopts, *a priori*, the Principle of energy conservation.

There are E – the energy of light emitted by the nearby or distant galaxy towards the Earth and measured by the Earth observer at present and E_G – the energy of this light when was emitted by the galaxy at time t (or in the cosmological past) and estimated by this observer knowing the value of E. These energies are given by

$$E = h\nu \text{ and } E_G = h\nu_G$$

where h (= 6.63×10^{-34} J sec) is Planck's constant and ν_t and ν are the corresponding frequencies.

At last, we know that the frequency equals the speed of light divided by the wavelength or $\nu = c/\lambda$. By the Principle of energy conservation $E_G = E$ or $\nu_t = \nu$. If we denote with λ_t and c_t the wavelength and the speed of light emitted by nearby or distant galaxies (in their cosmological past) then we have $\nu = c_t/\lambda_t = c/\lambda$ or $c_t/c = \lambda_t/\lambda$.

Let D_G stand for the distance (hereinafter distance) at time t in the cosmological past between the nearby or distant galaxy and the Earth. Combining $c_t/c = \lambda_t/\lambda$ with $z_G = (\lambda - \lambda_t)/\lambda_t$ [(derived from eqn (1)] we arrive at

$$c_t = c/(1 + z_G) \quad \dots (2)$$

Hence, from the perspective of the Earth's observer, the speed c_t of the light emitted by the nearby or distant galaxy at time t in the cosmological past is lower than the (current) speed of this light c reaching the Earth. If $z_G \rightarrow 0$, $c_t \rightarrow c$ and if $z_G \rightarrow \infty$, $c_t \rightarrow 0$. Thus, for the Earth's observer, the speed of light is not constant throughout the Universe, but variable in time.

In the near or distant cosmological future, the speed of light emitted by the nearby or distant galaxy reaching the Earth will be greater than c.[2] For the initial speed of this light to be the same, the speed at which it reaches the Earth must be proportional to (1 + its redshift). This and related issues will be considered in our separate communication.

By symmetry, from the perspective of the galaxy's observer, the speed of light, c_t, emitted by our Milky Way is lower for $(1 + z_G)$ than the speed of this light reaching the galaxy c in its present time. There is no reason why these two speeds would be the same for these observers in their reference frames. This is by Newtonian as well as with Einstein's physics.

The galaxy's light will cover the distance D_G with an average speed $c_{av} = [c_t + c)]/2 < c$. Since this speed is less than the current speed of light c, light from the galaxy will travel D_G longer time. So, the light will take longer to cover the distance D_G than if its speed is c. In other words, we deal with cosmological (or cosmic) time dilation. This dilation can be expressed by the following relation

$$\tau_C = D_G(1/c_{av} - 1/c) \quad \dots (3)$$

(or $\tau = [c - c_t][c + c_t))](D_G/c)]$.[3]

As the cosmological redshift of nearby and distant galaxies, $z_{G,}$ increases with their distance to the Earth, the speed of their emitted light will simultaneously increase with this distance.

Hubble's constant H_0 (= 7×10^{-11} y^{-1}) represents the constant rate of the space expansion. The subscript "0" indicates the value of the Hubble constant today. The terms $1/H_0$ and c/H_0 are the current age of the Universe and the current radius of the Hubble sphere (or the current Hubble's length), respectively. For the above value of H_0 and the current speed of light c, their values are about 13.8 Gy and 13.8 Gly.

When the galaxy with z_G emitted light, the size of the Universe was $1/(1 + z_G)$th of its current size or the radius of the Hubble sphere was about $1/(1 + z_G)$th of its current radius. In other words, the ratio of the current radius of the Hubble sphere, $R_H(0)$, and the radius of this sphere in the cosmological past, $R_H(t)$ is equal $1 + z_G$. In expression,

$$R_H(0)/R_H(t) = 1 + z_G$$

or

[2] The redshift of some nearby galaxies $z_G \leq 0.01$ then in their cases $(1 + z_G) \approx z_G$.

[3] For the nearby galaxies, the Hubble law is valid. By this law, the Hubble constant H_0 is the constant of proportionality between the cosmological redshift z_G of a nearby galaxy and its distance D_G to the Earth or $z_G = [(H_0D_G/c]$. Combining this equation with eqn. (2), we find that $c_t = c^2/(c + H_0D_G)$. For the nearby galaxies with $z_g \leq 0.01$ $c_t \approx c$.

$$R_H(t)/R_H(0) = c_t/c \quad \dots (4).$$

We know that $c_t/c = \lambda_t/\lambda$ then

$$\lambda/\lambda_t = R_H(0)/R_H(t) = 1 + z_G.$$

This equation corresponds to the equation

$$\lambda/\lambda_t = S_o/S_t = 1 + z_G$$

where S_t and S_0 are the scale factor values at the time t when the light was emitted by a nearby or distant galaxy and the time t_0 when it was detected by the Earth's observer ($t > t_0$).

According to the Friedmann–Lemaître–Robertson–Walker metric, which is used to model the expanding Universe, if at present we receive light with a redshift of z_G, then the scale factor at the time the light was originally emitted is given by

$$S_t = 1/(1 + z_G).$$

Multiplying this equation with the speed of light c we get

$$cS_t = c/(1 + z_G) = c_t.$$

The number of periods would be identical for $R_H(t)$ and $R_H(0)$. As we noted above, the speed of light divided by the frequency equals the wavelength of light (or $\nu = c/\lambda$) then the number of their wavelengths would be also the same. In expression,

$$R_H(0) = \mathcal{N}\lambda \text{ and } R_H(t) = \mathcal{N}\lambda_t$$

where $\mathcal{N}$ can be approximated as a very large natural number if it is larger or equal to say 10^4 [5].

Examples:

1. As one of the direct distance measurement methods, the “megamaser” method has demonstrated its capability for precise distance measurement of nearby galaxies. However, it appears this method is suitable for very few of these galaxies - “megamaser” galaxies. For the present case, we select two “megamaser” galaxies with a negligible peculiar speed: the closest NGC 1052 and the farthest NGC 6264 [6].
   NGC 1052 has $z_G = 0.00493$ and $D_G = 65$ Mly. Applying eqn. (2), we calculated that the speed of light emitted by this galaxy is about 298000 km sec^{-1} and the average speed of this light to the Earth is (300000 km sec^{-1} + 298000 km sec^{-1})/2 ≈ 299000 km sec^{-1}. The

time dilation of light from NGC 1052, calculated using eqn. (3), is about 0.43 ky. Using eqn. (4) we found that the radius of its Hubble sphere: 13.8 Gly/1.0043 ≈ 13.7 Gly.

2. NGC 6264 has z_G = 0.0338 and D_G = 447 Mly. Using the same equations as above we find that the speed of its light is about 290000 km sec^{-1} and the average speed of this light to the Earth is about (300000 km sec^{-1} + 299000 km sec^{-1})/2 ≈ 299000 km sec^{-1}. The time dilation of light from this galaxy, calculated by eqn. (3), is about 3 ky. Using eqn. (4) we found the radius of its Hubble sphere is: 13.8 Gly/1.0338 ≈ 13.4 Gly.

3. The quasar APM 08279+5255 has z_G = 3.91. Its age of about 12 Gy was determined by measuring the Fe/O ratio [7, and references therein]. Applying eqn. (2), we find that the speed of light emitted by APM 08279+5255, c_{APM} ≈ 61000 km sec^{-1} and the average speed of this light to the Earth is about (300000 km sec^{-1} + 61000 km sec^{-1})/2 ≈ 180000 km sec^{-1}. The light-travel distance is about 12 Gly ≈ 137 × 10^{23} km. However, we suggest that this distance is smaller and can be calculated by the following formula 12c_{AV} ≈ 732 × 10^{21} km. The cosmological redshift of APM 08279+5255 z_{APM} = 3.91 implies that the Universe expanded about 4.9 times between the emission of the light by this quasar and the observation of the same light by the Earth's observer. Using eqn. (4) we found that the radius of its Hubble sphere is: 13.8 Gly/4.9 ≈ 2.8 Gly.

In all current cosmological models, the recessional speed of distant galaxies with z_G > 1.5 exceeds the speed of light [8]. (Although there are still many debatable questions on this issue). Hence, this speed of APM 08279+5255 with z_G = 3.91 exceeds the speed of light at present time and in the cosmological past. Of course, the motion of this galaxy at present time does not affect the light that it emitted 12 Gy ago.

Using the above data for NGC 1052 and APM 09279+5255 we estimate that the speed of light increased by about 2 cm sec^{-1} y^{-1} for about the last 12 Gy. Of note, that Sanejouand [7] estimated that this speed decreased by nearly 2−3 cm sec^{-1} y^{-1} for about the last 12.8 Gy.

Conclusions

If we apply the Principle of energy conservation, then we show that the speed of light c_t emitted by nearby or distant galaxies at time t in the cosmological past is lower than the (current) speed of this light c reaching the Earth. The extent of this lowering depends on the factor (1 + z_G). The Hubble sphere was smaller in the past than today for the same factor. We estimate that the speed of light increased by nearly 2 cm sec^{-1} y^{-1} for about the last 12 Gy.

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