Another Explanation of the Cosmological Redshift

April 6, 2010.

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The loss of energy of the photon with the time by emission of heat to the intergalactic space might explain the cosmological redshift.

Key words: cosmological redshift, emission of heat.

1. Introduction

Generally, it is considered that the universe was originated in the Big Bang, and since then it is expanding. In that theory, the redshift of the light emitted from distant galaxies, the so-called cosmological redshift, is interpreted as a Doppler effect and then considered as an indication of the expansion of the universe, following the law of Hubble.

The light redshift parameter is defined as

$$z = \frac{\nu_e - \nu_o}{\nu_o} \tag{1.1}$$

being ν_e and ν_o the light frequencies emitted and observed, respectively; but as $c = \lambda\nu$, being *c* the light speed in vacuum, λ the wavelength and ν the frequency, then also

$$z = \frac{\lambda_o - \lambda_e}{\lambda_e} \tag{1.2}$$

being λ_e and λ_o the light wavelengths emitted and observed, respectively.

For the relativistic Doppler effect [1] (p. 166)

$$z = \frac{1 + v\cos\theta/c}{\sqrt{1 - v^2/c^2}} - 1 \tag{1.3}$$

being v the speed of the light source and θ the angle of the motion. For a motion in the line of sight ($\theta = 0$) and with $v << c$ (which corresponds to low redshift, $z << 1$)

$$z = \frac{v}{c} \tag{1.4}$$

The Hubble's law is stated as [1] (p. 486)

$$v_r = Hd \tag{1.5}$$

where v_r is the velocity of recession, namely the speed at which a light source moves away from the observer, due to the expansion of the space between both; H is the Hubble's constant, and d is the distance between the observer and the light source. For low redshift ($z << 1$) [1] (p. 486)

$$z = \frac{v_r}{c} = \frac{Hd}{c} \tag{1.6}$$

therefore, the redshift of the galaxies is proportional to their distances to the observer. That is, the greater the distance, the greater the redshift. From (1.4) and (1.6) we would have that $v_r = v$. As the distance from a galaxy to us, for a light signal, is

$$d = ct \tag{1.7}$$

being t the time, then

$$z = Ht \tag{1.8}$$

However, in this simple note, we are going to consider, using only very elementary arguments, that the redshift in the light coming from the stars might be produced by the loss of energy of the photon with the time by emission of heat.

2. The loss of energy of the photon with the time

The first principle of thermodynamics states that

$$\Delta U = \Delta Q - \Delta W \tag{2.1}$$

being U the internal energy, Q the heat and W the work, all of them referred to a given system. It expresses that the increment of the internal energy of the system is equal to the heat absorbed minus the work done.

Applying this principle to a photon traveling in the intergalactic space (IGS), we would have that

$$\Delta U = \Delta Q < 0 \tag{2.2}$$

because we consider that the photon does not make any work ($\Delta W = 0$) and emits heat to the IGS. The photon loses energy.

From the principle of equipartition of the energy, for a photon

$$U = h\nu = (3/2)k_B T \tag{2.3}$$

being h the Planck's constant, k_B the Boltzmann's constant and T the absolute temperature (Kelvin's temperature).

From (2.2) and (2.3)

$$\Delta\nu = (3/2)k_B \Delta T/h < 0 \tag{2.4}$$

and the photon undergoes a redshift.

From (1.1) and (1.8)

$$\nu_e = \nu_o + \nu_o Ht \tag{2.5}$$

which expresses a linear decrease of the frequency of the photon with the time. From (2.3)

$$\nu_e = (3/2)k_B T_e/h \tag{2.6}$$

$$\nu_o = (3/2)k_B T_o/h \tag{2.7}$$

being T_e and T_o the absolute temperatures of the photon at the points of emission and observation, respectively, and substituting (2.6) and (2.7) into (2.5)

$$T_e = T_o + T_o Ht \tag{2.8}$$

and the decrease in frequency is a decrease in temperature, or in other words, the photon loses energy by emission of heat. As (2.5) is valid only for $z << 1$, the same happens with (2.8).

For any redshift, the heat equation would be

$$\frac{\partial T}{\partial t} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \tag{2.9}$$

where a is a constant, and x, y and z the spatial coordinates. And for only t and x

$$\frac{\partial T}{\partial t} = a\frac{\partial^2 T}{\partial x^2} \tag{2.10}$$

By separation of variables

$$T(t,x) = f(t)g(x) \tag{2.11}$$

Substituting (2.11) into (2.10)

$$\frac{df(t)}{af(t)dt} = \frac{d^2 g(x)}{g(x)dx^2} \tag{2.12}$$

Since the left hand side depends only on *t* and the right hand side only on *x*, both sides are equal to some constant value *b*

$$\frac{df(t)}{af(t)dt} = \frac{d^2 g(x)}{g(x)dx^2} = -b \tag{2.13}$$

from which we would have

$$f(t) = Ae^{-abt} \tag{2.14}$$

$$g(x) = B\cos\left(b^{1/2}x + C\right) \tag{2.15}$$

being *A*, *B* and *C* integration constants.

As $x_{\max.} = \lambda$, $T(t,x) \cong T(t,0) = f(t)g(0) = AB\cos Ce^{-abt} = T(t)$. For $t = 0$, $T(0) = AB\cos Ce^{-ab0} = AB\cos C$ and

$$T(t) = T(0)e^{-abt} \tag{2.16}$$

But as $T_e = T(0)$ and $T_o = T(t)$

$$T_o = T_e e^{-abt} \tag{2.17}$$

$$T_e = T_o e^{abt} \tag{2.18}$$

For $abt << 1$

$$T_e = T_o(1 + abt) = T_o + T_o abt \tag{2.19}$$

which is the same as (2.8) with

$$ab = H \qquad (2.20)$$

Therefore, for low redshift we may use (2.5), (2.8) and

$$z = \frac{\nu_e - \nu_o}{\nu_o} = \frac{T_e - T_o}{T_o} = Ht \qquad (2.21)$$

And for high redshift

$$T_e = T_o e^{Ht} \qquad (2.22)$$

$$\nu_e = \nu_o e^{Ht} \qquad (2.23)$$

$$z = \frac{\nu_e - \nu_o}{\nu_o} = \frac{T_e - T_o}{T_o} = e^{Ht} - 1 \qquad (2.24)$$

where (2.23) is obtained substituting (2.6) and (2.7) into (2.22). Substituting (1.7) into (2.24)

$$z = \frac{\nu_e - \nu_o}{\nu_o} = \frac{T_e - T_o}{T_o} = e^{(H/c)d} - 1 \qquad (2.25)$$

and the redshift increases exponentially with the distance.

For a redshift value of $z = 1{,}088$ for the cosmic microwave background radiation (CMBR), which would correspond to the redshift of the light emitted by the light sources located on a circumference centered at the Earth of radius $d = (c/H)\ln(1+z) = (c/H)\ln 1{,}089$, the corresponding relation of temperatures would be $T_o = T_e/e^{Ht} = T_e/(1+z) = T_e/1{,}089$. For $h = 6.625\times10^{-34}$ *joules sec*, $k_B = 1.380\times10^{-23}$ *joules/ºK* and $\nu_e = 10^{14}$ *cycles/sec*, from (2.6), $T_e = 3{,}200$ *ºK*, and $T_o = 2.9$ *ºK*.

In summary, the key is to consider *H* as a constant related with the loss of energy of the photon but due to the emission of heat not to the expansion of the universe.

3. Conclusion

We conclude that the loss of energy of the photon with the time by emission of heat to the IGS might explain the cosmological redshift.

References

[1] L. D. Landau and E. M. Lifshitz, Teoría clásica de los campos, in Spanish, second edition, Editorial Reverté, S. A., Barcelona (1973). Original edition by Nauka, Moscow.