Light propagated distance and redshift of a distant star

Shigeto Nagao
Ishibashi, Ikeda, Osaka, 563-0032 Japan
E-mail: snagao@lilac.plala.or.jp

Abstract. According to the formerly reported 4-D spherical model of the time and universe, factors affecting the redshift are discussed. In addition to the factor from the space expansion, two other factors derived from the light speed variation are proposed. One is the energy density factor of the wave medium, which was formerly reported to determine the light speed. The second is a newly proposed factor caused by the electromagnetic interaction of light with substances in the 3-D space. Subsequently the direct correlation of the light propagated distance with the redshift is given. Superimposed graphs of it on the real observed data from the Supernova Cosmology Project exhibited an excellent fit for a case that the current radius (equal to our observed time) of the universe is between 0.7 and 0.8 of its maximum. This could be an important ground for a possibility of the 4-D spherical model, which implies that the universe has been expanding at a constant speed by our observed time.

1. Introduction

The author of this article formerly proposed a model of the time and universe, in which the space energy ("Spacia") is spread with expansion in a 3-dimensional surface of a 4-dimensional sphere ("4-D Spherical Model" or "4DS Model"") [1, 2]. What we detect as energy in the 3-D space is a vibration of the intrinsic space energy in the 3-D space. What we observe as the time passing at a constant speed ("Time") is the radius dimension of the 4-D sphere for the distribution of the space energy. Space expansion is proportional to the Time as shown by \( |r| = |x| \theta \), where \( \theta \) denotes the angle from the center of universe for a 3-D space vector \( r \) and \( x \) is the radius of the 4D sphere of universe equal to the Time. The model insists on the changing speed of light propagation in accordance with the expansion of the universe. Due to the existence of the wave medium for energy in the 3-D space there is a special frame stationary to the intrinsic space energy Spacia. According to the model, I further proposed previously to abandon the Special Relativity and newly introduce the acceleration factor \( f_a \) shown by eqs. (1) and (2) as a feature of wave [3],

\[
\alpha = \frac{F}{m f_a}, \quad F = \frac{m}{f_a} \alpha \tag{1}
\]

\[
f_a = \left(1 - \frac{v^2}{c^2}\right)^n \quad (n \geq 1) \tag{2}
\]

In the former article of ref. [2], it was shown that the light propagated distance from a distant star is not proportional to the time passed since it was emitted due to the changing speed of light.
The formulas and graphs shown there were not direct relations of the light propagated distance with the redshift but with the time passed since emission. In this article, factors affecting the redshift are discussed and the graph of light propagated distance versus redshift, which are the real observables in the Supernova Cosmology Project, is given.

In the section 4 for discussion, the reason why the Michelson-Morley type experiments are incapable to detect a shift of interference fringe is also discussed because the presence of a wave medium for light and other energy in 3D space is a prerequisite for the proposed 4DS Model.

2. Redshift

2.1. Definition of terms related to Time

At the beginning, define the following terms and abbreviations related to Time.

- $x$ (Radius of universe): Radius of the 4D sphere of universe, equal to the Time ($T$).
- $CU$ (Cosmic Unit): Unit of $x$ and $T$, being 1 at its maximum. (Time-related variables are expressed in the CU in this article.)
- $T_E$ (Time of Emission): Time when the light was emitted.
- $T_P$ (Present Time): Present Time of universe, when the light reaches us.
- $T_{ER}$ (Relative Time of Emission): Relative ratio of $T_E$ to $T_P$. $T_{ER} \equiv T_E/T_P$
- $T_B$ (Back in Time): Back in Time from present for $T_E$. $T_B \equiv T_P - T_E$
- $T_{BR}$ (Relative Back in Time): Relative ratio of $T_B$ to $T_P$. $T_{BR} \equiv T_B/T_P$
- $T_C$ (Time Clear): Time when the space became transparent to light.
- $T_{CR}$ (Relative Time Clear): Relative ratio of $T_C$ to $T_P$. $T_{CR} \equiv T_C/T_P$

2.2. Wavelength and frequency

As potential factors affecting the redshift there would be three types; Doppler effect, the space expansion and the speed of light. In case of inter-galaxy observation, Doppler effect due to the relative velocity to the wave medium can be neglected. Both the emitter and the observer can be regarded stationary to the wave medium Spacia at their respective positions. In the current cosmology, only the space expansion is considered as a factor for redshift along with adjustment from the theory of relativity because the light speed is regarded constant. However, the factor by light speed variation should be taken into consideration according to the 4DS Model.

In general for wave, the wave propagation speed is proportional to the wavelength whereas the frequency remains constant only depending on the emitter, shown as

$$v = f \times \lambda \ .$$

(3)

This is a case for light propagation in a substance like water or glass as well as for sound propagation. From the factor of light speed variation, the frequency remains constant whereas the wavelength changes. On the other hand, from another factor corresponding to the space expansion itself, the light speed is not altered but the wavelength is expanded and the frequency is decreased. Combined the two factors, the change of frequency and that of wavelength since the light was emitted are shown by the following equations

$$\frac{f(T_P)}{f(T_E)} = \frac{1}{n} \quad (4)$$

$$\frac{\lambda(T_P)}{\lambda(T_E)} = n \times \frac{C(T_P)}{C(T_E)} \quad (5)$$

in which $n$ denotes the "Space expansion ratio" defined by $n \equiv T_P/T_E$. 


2.3. Light speed

The light propagation speed should be affected by the energy density of the medium ("Energy density factor" or "\( f_D \)) and also by electromagnetic interaction of light with substances in 3-D space ("Electromagnetic interaction factor" or "\( f_{EM} \)). I propose that the light speed by our observed Time is expressed by the following formula

\[
C(T) = C(x) = \frac{dL}{dx} = K \ast f_D \ast f_{EM}, \tag{6}
\]

where \( K \) is a constant. The Energy density factor \( f_D \) was discussed in my former articles [1] and [2], and is given by the following formula using the Cosmic Unit (CU) for \( x \). When the universe stops expansion due to gravity, \( x \) takes its maximum value 1 in the CU.

\[
f_D = \frac{1}{x\sqrt{1-x}} \quad (T_C \leq x < 1) \tag{7}
\]

An example of the Electromagnetic interaction factor \( f_{EM} \) is the fact that light propagates slower in the water or glass than in vacuum. Light interacts with substances and receives scattering, which results in slowing propagation speed. Before the formation of hydrogen atoms, the space of universe was not transparent to light propagation due to interaction of light with electrons and protons in plasma. After completion of atom formation, the space became cleared up for light. It is generally said that the Cosmic Microwave Background (CMB) radiation started to go straight around 370,000 years after the Big Bang. The temperature of the universe was around 3,000 K at the time, corresponding to an energy of about 0.25 eV, which is much less than the 13.6 eV ionization energy of hydrogen [4]. At the early time known as "the time of last scattering”, light could not go straight even after the completion of plasma conversion to atoms. This can be interpreted due to high density of atoms. In accordance with the space expansion, the incidence of light to interact with atoms should decrease corresponding to the descending density of atoms. We could expect the incidence is reversibly proportional to the cube of the radius \( x \). Furthermore, when the CMB radiation started (\( x = T_C \)), the Electromagnetic interaction factor would be zero. I propose the following formula for \( f_{EM} \).

\[
f_{EM} = 1 - \frac{T_C^3}{x^3} \quad (T_C \leq x < 1) \tag{8}
\]

If CMBR started 370 thousand years after the Big Bang and the current universe is 13.8 billion years old [4], \( T_{CR} \) would be \( 2.68 \times 10^{-5} \). However, it would be likely that current universe is regarded older than the real one due to the lack of adjustment of changing speed of light. Let’s take a second scenario for a larger \( T_{CR} \) value corresponding to one million years for the initial CMBR and 10 billion years for the age of current universe, which gives \( 1 \times 10^4 \) for \( T_{CR} \).

\[
T_{CR}(1) = \frac{3.7 \times 10^{-5} \text{years}}{1.38 \times 10^{-10} \text{years}} = 2.68 \times 10^{-5} \tag{9}
\]

\[
T_{CR}(2) = \frac{1 \times 10^{-6} \text{years}}{1 \times 10^{-10} \text{years}} = 1 \times 10^{-4} \tag{10}
\]

From eqs. (6), (7) and (8), the following formula is given for the light speed.

\[
C(x) = K \ast \frac{1}{x\sqrt{1-x}} \ast \left(1 - \frac{T_C^3}{x^3}\right) \tag{11}
\]

We don’t know yet either \( T_C \) or \( T_P \). If \( T_{CR} \) is \( 2.68 \times 10^{-5} \) and \( T_P \) is 0.75, then \( T_C \) is \( 2 \times 10^{-5} \). In Fig. 1, a graph of light speed versus the radius \( x (= T) \) in semi-logarithmic scale is given.
Figure 1. Time-course of light speed by the Time. Left: Whole range graph of light speed for the Time Clear $T_C = 2 \times 10^{-5}$. The maximum in small $x (= T)$ value area is not correctly shown due to limitation of sampling points. Right: Enlarged graphs in small $x (= T)$ value area for $T_C = 10^{-5}$ to $2 \times 10^{-4}$. The dotted line in black is for the case of $f_{EM} = 1$. The right part is an enlarged graph in very small area of $x$ for plural $T_C$ values from $10^{-5}$ to $2 \times 10^{-4}$. The dotted line in black represents the light speed graph for $f_{EM} = 1$. As shown in the graph, for the area of $x$ greater than $5 \times 10^{-4}$, the effect of $f_{EM}$ can be ignored and treated as $f_{EM} = 1$ subject to $T_C \leq 2 \times 10^{-4}$. For $x \geq 5 \times 10^{-4}$, light speed can be treated as 

$$C(x) = \frac{K}{x \sqrt{1 - x}}. \quad (12)$$

2.4. Redshift

The prolongation ratio of wavelength at $T_P$ from $T_E$ is given as follows from eqs. (5) and (11).

$$\frac{\lambda(T_P)}{\lambda(T_E)} = \frac{n \times C(T_P)}{C(T_E)} = \frac{T_P}{T_E} \times \frac{T_E \sqrt{1 - T_E}}{T_P \sqrt{1 - T_P}} \times \frac{1 - (T_P/E)^3}{1 - (T_C/E)^3} = \frac{\sqrt{1 - T_P}}{\sqrt{1 - T_P}} \times \frac{1}{1 - (T_C/E)^3} \quad (13)$$

Because $T_{CR}$ is expected smaller than at least $10^{-3}$, $T_{CR}^3$ in $1 - T_{CR}^3$ of eq. (13) can be ignored. The redshift $z$ is given as follows.

$$z + 1 = \frac{\lambda(T_P)}{\lambda(T_E)} = \frac{\sqrt{1 - T_P T_{ER}}}{\sqrt{1 - T_P}} \times \frac{1}{1 - (T_C/E)^3} \quad (14)$$

$$z = \sqrt{1 + \frac{T_P(1 - T_{ER})}{1 - T_P}} \times \frac{1}{1 - (T_C/E)^3} - 1 \quad (15)$$

Replacing $T_{ER}$ by $T_{BR}$, we get the following equation.

$$z = \sqrt{1 + \frac{T_P T_{BR}}{1 - T_P}} \times \frac{1}{1 - (T_C/E)^3} - 1 \quad (16)$$

Graphs of redshift $z$ versus $T_{BR}$ for various $T_P$ values are given in Fig. 2. The left graph is for $T_C = 2.68 \times 10^{-5}$, but it is almost same as that for $T_C = 1 \times 10^{-4}$ in this scale. The right graph is in very large $T_{BR}$ area greater than 0.999 for $T_C = 2.68 \times 10^{-5}$ and $T_C = 1 \times 10^{-4}$.
Figure 2. Redshift versus the Relative Back in Time ($T_{BR}$). **Left**: Whole range graph of redshift for the Relative Time Clear $T_{CR} = 2.68 \times 10^{-5}$. **Right**: Enlarged graph in high $T_{BR}$ area for $T_{CR} = 2.68 \times 10^{-5}$ and $T_{CR} = 1 \times 10^{-4}$.

with $T_P = 0.7$ or 0.8. Redshift values for some representing $T_{ER}$ values are given in Table 1. As we see in the figure and the table, for the area of $T_{ER}$ greater than 0.001 (or $T_{BR} \leq 0.999$), we can ignore the influence by $f_{EM}$, and $z$ can be approximated to be

$$z \approx \sqrt{1 + \frac{T_P T_{BR}}{1 - T_P} - 1}.$$  

(17)

Table 1. Redshift $z$.

| $T_{CR} = 2.68 \times 10^{-5}$ (corresponding to $3.7 \times 10^{7}$/year/$1.38 \times 10^{10}$/year) |
| $T_P$ | 0.1 (1380MY) | 0.01 (138MY) | 0.001 (13.8MY) | $1 \times 10^{-4}$ (1.38MY) | $5 \times 10^{-5}$ (0.69MY) | $3 \times 10^{-5}$ (0.414MY) | $2.7 \times 10^{-5}$ (0.373MY) |
|-------|----------|----------|----------|----------|----------|----------|----------|
| 0.6   | 0.533    | 0.576    | 0.581    | 0.612    | 0.869    | 4.508    | 70.680   |
| 0.7   | 0.761    | 0.819    | 0.825    | 0.862    | 1.158    | 5.360    | 81.769   |
| 0.8   | 1.145    | 1.227    | 1.235    | 1.280    | 1.643    | 6.789    | 100.371  |

| $T_{CR} = 1 \times 10^{-4}$ (corresponding to $1 \times 10^{5}$/year/$1 \times 10^{10}$/year) |
| $T_P$ | 0.1 (1000MY) | 0.01 (100MY) | 0.001 (10MY) | $2 \times 10^{-4}$ (2MY) | $1.1 \times 10^{-4}$ (1.1MY) | $1.01 \times 10^{-4}$ (1.01MY) |
|-------|----------|----------|----------|----------|----------|----------|
| 0.6   | 0.533    | 0.576    | 0.582    | 0.807    | 5.358    | 52.761   |
| 0.7   | 0.761    | 0.819    | 0.827    | 1.086    | 6.341    | 61.077   |
| 0.8   | 1.145    | 1.227    | 1.237    | 1.555    | 7.991    | 75.028   |

3. Light propagated distance
Light propagated distance of a star, which we detect now, is given as

$$L(T_E) = \int_{T_E}^{T_F} C(x) dx = \int_{T_E}^{T_F} \frac{K}{x \sqrt{1 - x}} \left(1 - \frac{T_C^3}{x^3}\right) dx.$$  

(18)
If \( T_{ER} \geq 10^{-3} \) or \( T_{BR} \leq 0.999 \), we can approximate it as

\[
L(T_E) \approx \int_{T_E}^{T_P} \frac{K}{x\sqrt{1-x}} dx .
\]

(19)

As shown in the reference [2], eq. (19) is written by \( T_{BR} \) as follows.

\[
\int \frac{1}{x\sqrt{1-x}} dx = \log \left( \frac{1 - \sqrt{1-x}}{1+\sqrt{1-x}} \right) + k
\]

(20)

\[
L(T_{BR}) = K \cdot \log \left( \frac{1 - \sqrt{1 - T_P}}{1 + \sqrt{1 - T_P}} \cdot \frac{1 + \sqrt{1 - T_P + T_P T_{BR}}}{1 - \sqrt{1 - T_P + T_P T_{BR}}} \right)
\]

(21)

From eq. (17), \( T_{BR} \) is replaced by \( z \) as

\[
(z + 1)^2 = 1 + \frac{T_P T_{BR}}{1 - T_P}
\]

(22)

\[
T_{BR} = \frac{(1 - T_P) z(z + 2)}{T_P} .
\]

(23)

Putting eq. (23) into eq. (21), we get the following formula of light propagated distance versus the redshift for the range of \( T_{ER} \geq 10^{-3} \) or \( T_{BR} \leq 0.999 \).

\[
\sqrt{1 - T_P + T_P T_{BR}} = \sqrt{1 - T_P + (1 - T_P) z(z + 2)}
\]

(24)

\[
L(z) = K \cdot \log \left( \frac{1 - \sqrt{1 - T_P}}{1 + \sqrt{1 - T_P}} \cdot \frac{1 + \sqrt{1 - T_P + (1 - T_P) z(z + 2)}}{1 - \sqrt{1 - T_P + (1 - T_P) z(z + 2)}} \right)
\]

(25)

Because we don’t know yet the value of \( K \), let’s take the relative light propagated distance to that at \( z = 0.05 \) (“RLD”) in order to superimpose its graph on the observed data from the Supernova Cosmology Project [5].

\[
RLD \equiv \frac{L(z)}{L(0.05)} = \log \left( \frac{1 - \sqrt{1 - T_P}}{1 + \sqrt{1 - T_P}} \cdot \frac{1 + \sqrt{1 - T_P + (1 - T_P) z(z + 2)}}{1 - \sqrt{1 - T_P + (1 - T_P) z(z + 2)}} \right) \times \left( \log \left( \frac{1 - \sqrt{1 - T_P}}{1 + \sqrt{1 - T_P}} \cdot \frac{1 + \sqrt{1.1025(1 - T_P)}}{1 - \sqrt{1.1025(1 - T_P)}} \right) \right)^{-1}
\]

(26)

Its graphs for \( T_P = 0.6, 0.7, 0.8 \) and 0.9 are given in Fig. 3. Respective \( T_{ER} \) values corresponding to \( z = 0.05 \) for \( T_P = 0.6, 0.7 \) and 0.8 are shown in Table 2. RLD values respectively for \( T_{ER} = 0.1, 0.01 \) and 0.001 are also shown in Table 2 for \( T_P = 0.6, 0.7 \) and 0.8. As we see there, if the RLD value is smaller than about 65, \( T_{ER} \) should be greater than 0.001 subject to \( T_P \geq 0.6 \). For the area, we can ignore the effect by \( f_{EM} \), and the approximation expressed by eq. (26) can be applied. In Fig. 3, RLD graphs for \( RLD \leq 50 \) and \( z \leq 1.17 \) are shown in dual logarithmic scale.

For the small \( z \) range \( z \leq 0.05 \), not only \( f_{EM} \) but also the influence of \( f_D \) to light speed variation can be ignored. Light speed can be regarded constant and the RLD is given as follows.

\[
L = c(T_P - T_E) = cT_P T_{BR}
\]

(27)

\[
T_{BR} = \frac{T_B}{T_P} = \frac{z}{z + 1}
\]

(28)
Figure 3. Relative light propagated distance (RLD) versus redshift.

Table 2. Relative light propagated distance \( RLD = L(z)/L(0.05) \).

| \( T_P \) | \( T_{ER \atop z = 0.05} \) | 0.1 | 0.01 | 0.001 | \( T_{CR(2)} = 10^{-4} \) | \( T_{CR(1)} = 2.68 \times 10^{-5} \) |
|---|---|---|---|---|---|---|
| 0.6 | 0.93167 | 24.5 | 45.9 | 67.0 | < 88.1 | < 100.2 |
| 0.7 | 0.95607 | 34.7 | 63.9 | 92.7 | < 121.5 | < 138.0 |
| 0.8 | 0.97438 | 51.4 | 92.7 | 133.4 | < 174.1 | < 197.3 |

\[
RLD = \frac{c T_P T_{BR}}{c T_P \cdot 0.05 \cdot 1.05} = \frac{21 \cdot T_{BR}}{21 \cdot \frac{z}{z + 1}} = 21 \cdot T_{BR} = 21 \cdot \frac{z}{z + 1} \tag{29}
\]

Superimpose RLD versus \( z \) graphs in a way that they match to the observed data for various \( T_P \) values in the area \( z \leq 0.05 \) because eq. (29) is independent of \( T_P \). The results are shown in Fig. 4. The observed data give an excellent fit to the expectation for a case that \( T_P \) is between 0.7 and 0.8 in the range \( RLD \leq 50 \). The dotted line in black in Fig. 4 is the graph of eq. (29), which would be applicable if light speed had been constant.

Provided that the current Time \( T_P \) is roughly 0.75, the \( K \) value for light speed is given as follows from eq. (12), where \( c \) denotes the current light speed.

\[
K = \left(0.75 \times \sqrt{0.25}\right) \cdot c \approx 0.375 \times c \approx 1.125 \times 10^{8} m/s^{-1} \tag{30}
\]

How would be the RLD in a case \( 0.001 > T_{ER} \geq T_{CR} \)? The redshift shown by eq. (15) diverges to infinity when \( T_E \) approaches to \( T_C \). On the other hand the light propagated distance shown by eq. (18) has at least the following upper limit.

\[
L(T_E) = \int_{T_E}^{T_P} \frac{K}{x \sqrt{1-x}} \left(1 - \frac{T_{C}^3}{x^3}\right) dx < \int_{T_E}^{T_P} \frac{K}{x \sqrt{1-x}} dx \leq \int_{T_E}^{T_P} \frac{K}{x \sqrt{1-x}} dx \tag{31}
\]

The RLD also has an upper limit when \( T_E \) approaches to \( T_C \).

\[
RLD = \frac{L(x = T_E)}{L(z = 0.05)} \leq \frac{1}{L(z = 0.05)} \int_{T_E}^{T_P} \frac{K}{x \sqrt{1-x}} dx \leq \frac{1}{L(z = 0.05)} \int_{T_C}^{T_P} \frac{K}{x \sqrt{1-x}} dx \tag{32}
\]

Values of the right side of eq. (32) are shown in Table 2 for \( T_{CR} \) is \( 10^{-4} \) or \( 2.68 \times 10^{-5} \).
4. Discussion and conclusion
The presence of the medium for light and other energy in the 3-D space is a prerequisite for the proposed 4DS Model. If the Michelson-Morley experiment has duly proved the absence of the light medium without any doubt as repeatedly confirmed by many scientists over more than 100 years [6]-[8], the 4DS Model is denied. Let’s check key points of the experiment, which were partly discussed previously in the reference [3], in a more comprehensive manner.

In the experiment, a light beam is split by a half-mirror into a straight beam and a reflected right angle beam. Both beams are reflected at the respective ends of arms, return to the half-mirror and are combined for detection [7, 8]. Firstly let’s see the experiment by the reference frame stationary to the medium and then by another frame fixed to the apparatus.

1) By the reference frame stationary to the medium
   -Phase propagation speed of a wave is constant independent of the speed of the emitter to the medium. Therefore, the light speed is constant by the medium’s frame.
   -The route of the beam A parallel to the apparatus movement is longer than the route of the perpendicular beam B for the round trip between the half-mirror and the end mirror. For details, please refer to the reference [3]. The beam A takes $\Delta t$ longer time than the beam B for the round trip.
   -The displacement of the beam A is released at the splitter $\Delta t$ earlier than that of the beam B is released so that the two displacements reach the same point at the same instance for interference detection. There is a phase difference of $\omega \Delta t$ between the two beams at the detector, where $\omega$ denotes the angular frequency of the beams [3].
   -The reflecting point at the end mirror varies by the time if the mirror moves toward the medium. Even if the reflecting point is varied, the reflected wave is shown by the same wave equation and the frequency remains constant. We can confirm it as follow. Take a wave shown by $A = \sin(x - vt)$. At $t = t_1$ the wave is reflected. The reflected wave is shown by $A = \sin(x + vt_1 + v(t - t_1)) = \sin(x + vt)$, which is independent of $t_1$, because reflected wave phase speed is $-v$ independent of the mirror speed to the medium.
   -In the case of Michelson-Morley experiment, the respective reflected beams have the same light speed and same frequency with the phase difference of $\omega \Delta t$. At the point where the
two beams are combined to interfere, the sum of amplitudes can be expressed as follows, where $A$ is the maximum amplitude of beam A and beam B.

$$U_a + U_b = A \sin \omega t + A \sin \omega (t + \Delta t)$$

$$= A \sin \left( \omega t + \frac{\omega \Delta t}{2} \right) + A \sin \left( \omega t + \frac{\omega \Delta t}{2} + \frac{\omega \Delta t}{2} \right)$$

$$= 2A \cos \frac{\omega \Delta t}{2} \sin \left( \omega t + \frac{\omega \Delta t}{2} \right)$$

(33)

- The combined wave can be shown as follows, where $x$ denotes the distance from the combined point in the direction to the interferometer and $k$ denotes the angular wave number given as $k = \omega/c$, in which $c$ is the light speed toward the medium. By the variation of $\Delta t$ there is no change of the frequency while the maximum amplitude and the phase vary.

$$U_a + U_b = 2A \cos \frac{\omega \Delta t}{2} \sin \left( kx - \omega t - \frac{\omega \Delta t}{2} \right)$$

(34)

2) By the frame fixed to the apparatus

- The light traveled distance is same for both the beams A and B by the apparatus’ frame.
- The time is same as that by the medium’s frame.
- The average light speed during the round trip between the half-mirror and the end mirror is different among the beams A and B shown by $c_A = 2L/(t+\Delta t)$ and $c_B = 2L/t$, respectively.
- However, the direction of light propagation at the detector is identical for the beam A and the beam B. Therefore, light speed at the detector is common for both beams.
- Therefore, the combined wave for detection can be also expressed similarly to eq. (34) as follows, where $U'_a, U'_b, k'$ and $x'$ are values measured by the apparatus’ frame. $k'$ is given as $k' = \omega/c'$, where $c'$ is the light speed by the apparatus' frame in the direction of $x'$.

$$U'_a + U'_b = 2A \cos \frac{\omega \Delta t}{2} \sin \left( k'x' - \omega t - \frac{\omega \Delta t}{2} \right)$$

(35)

3) Interference fringe

Either by the medium’s frame or the apparatus’ frame, there are following aspects for the interference fringe:

- The combined wave goes into the interferometer, and passes through the two slits with a very small distance.
- On the detection screen, interference fringe is shown.
- The location and pattern of the fringe depends on the slit pitch and the distance from the slits to the screen.
- The fringe pattern varies by the light frequency or wavelength, but is not altered by the variation of the phase of light.

As a conclusion, by the variation of $\Delta t$ no change of position of the interference fringe should be detected while the brightness of the fringe would be altered.

The latest modern Michelson-Morley type experiment would be the Herrmann et al’s experiment [9]. It concluded that the anisotropy of the speed of light $\Delta c/c$ is less than $1 \times 10^{-17}$. The experiment uses two laser emitters with two crossed orthogonal optical resonators that are implemented in a single block of fused silica instead of a single emitter and a splitter. For frequency comparison, split-off fractions of the two beams are overlapped on a photodiode to generate a beat note at a difference frequency [9]. In order to generate a beat note, the two beams
should be combined in the same direction. Therefore, by the apparatus’ frame the light speed at the beat note generator is common for the both beams even if respective light speeds in the two resonators are different. The reason why the Michelson-Morley like experiments should be incapable to detect the interference fringe shift is because the two beams are finally combined in a common direction for measurement of interaction. Because the direction is common for both beams, the respective light speeds by the apparatus’ frame are equal to each other at the detector. Difference in the route of beam before being combined causes only difference in phase.

It was striking to be shown from the Supernova Cosmology Project (SCP) by Perlmutter et al that the expansion of the universe was accelerating in spite of the gravitational attraction of the universe [10]- [13]. The dark energy resulting from an unknown repulsive force is proposed. Many attempts to rationale the new force are under investigation but no one has succeeded in a perfect form. There is another possibility to interpret the observed data from the SCP, that is, the light speed may be varied by the time passing since the light was emitted. According to the 4DS Model, light speed varies with space expansion due to the existence of the wave medium.

Light speed variation by the time was discussed in the reference [2]. In this article, the direct correlation between the light propagated distance and the redshift, which are the real observables in the SCP, was given. As a factor affecting the light speed, the electromagnetic interaction factor causing scattering by substances \( f_{EM} \) is newly introduced in addition to the formerly proposed energy density factor of the wave medium \( f_D \) for determining light speed. \( f_D \) and \( f_{EM} \) are expressed by eqs. (7) and (8), respectively. The light speed by our observed Time is expressed by eq. (11). The redshift is accordingly shown as eq. (15) or (16). Except for the very early time since the Big Bang, that is, in the range \( T_{ER} \geq 0.001 \) or \( T_{BR} \leq 0.999 \) \( f_{EM} \) can be ignored. The redshift value can be approximated to be eq. (17).

If \( T_{BR} \leq 0.999 \) for a supernova, the light propagated distance can be expressed by redshift as eq. (25). The relative light propagated distance to that of \( z = 0.05 \) (RLD) is finally derivatized to eq. (26) shown in Fig. 3. The RLD graph in a dual logarithmic scale has shown an excellent fit to the observed data from the SCP for the Present Time of universe \( T_P \) being between 0.7 and 0.8 as shown in Fig. 4. The SCP data should be a supportive evidence for a possibility that the universe has been expanding at a constant speed according to the 4DS Model.

I will highly appreciate other investigators to verify the relation of light propagated distance to redshift in more detail from observed data as well as any discussions and arguments.

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