The dichotomous cosmology with a static material world and expanding luminous world

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Abstract

The dichotomous cosmology is an alternative to the expanding Universe theory, and consists of a static matter Universe, where cosmological redshifts are explained by a tired-light model with an expanding luminous world. In this model the Hubble constant is also the photon energy decay rate, and the luminous world is expanding at a constant rate as in de Sitter cosmology for an empty Universe. The present model explains both the luminosity distance versus redshift relationship of supernovae Ia, and ageing of spectra observed with the stretching of supernovae light curves. Furthermore, it is consistent with a radiation energy density factor $(1+z)^4$ inferred from the Cosmic Microwave Background Radiation.

I. INTRODUCTION

Our model is inspired by the tired-light theory that was first proposed by [1] to explain cosmological redshifts, which has been subject to other investigations [2–4]. Generally, tired-light models describe a static Universe; however, in the present model only the matter component of the Universe is static, and the luminous component is expanding. The idea of a static Universe was proposed in Einstein's cosmological model [5], which is the first of the relativist cosmologies. Einstein had to introduce a cosmological constant to make his Universe static; otherwise it would have collapsed due to the gravitational field. Einstein came to the conclusion that his cosmology describes a spatially finite spherical Universe, as he encountered a degeneracy of coefficient $g_{\mu\nu}$ at infinity. Also, Poisson's equation, $\nabla^2\Phi = 4\pi G\rho$, where Φ is the scalar potential and ρ the matter density, played an important role in Einstein's cosmology. As Einstein's wrote in [5]: "It is well known that Newton's limiting condition of the constant limit for Φ at spatial infinity leads to the view that the density of matter becomes zero at infinity."

Let us do a simple thought experiment for inertial bodies in an infinite Universe that is isotropic and has no edge in Newton's absolute Euclidean space. Imagine you are a galaxy, there is a galaxy on your left and on your right, and both exert a gravitional force of same magnitude on you; the two forces would offset and you would not move from your position. From this view, based on the principle of inertia in an absolute Euclidean space, each galaxy in an isotropic Universe would be in this position of equilibrium, and the Universe would be static overall. However, for galaxy clusters where the cluster has an edge, we would expect that the galaxies will end up merging.

De Sitter introduced the concept of "relativity of inertia" based on his analysis of the degeneracy of the $g_{\mu\nu}$ at infinity in Einstein cosmology [6]. To overcome this problem, de Sitter found a solution by extending Einstein's cosmology in three-dimensional space to the four dimensional Minkowski space-time – a world of hyperboloid shape – and with no matter. De Sitter's cosmological model is a solution to Einstein's field equation applied to a vacuum, with a positive vacuum energy density, and describes an expanding Universe. Contemporary cosmological models based on general relativity such as the ΛCDM assume a uniform distribution of matter in space, but the effect of the deformation of space-time due to massive bodies may be preponderant only locally, hence this hypothesis may not be true. In special relativity, light moves along the geodesics of the Minkowski space-time, whereas matter is confined in the three-dimensional Euclidean space. From the equivalence principle in curved space-time, an inertial particle and a pulse of light both follow the same geodesic. Contrary to Newtonian physics which describe interactions between bodies, general relativity is often employed to describe the dynamics of light, such as the deflection of light, or the event horizon of black holes. In contrast, the theory of general relativity does not establish such a dichotomy beteween matter and light; based on the weak field approximation of general relativity [7], Newton's laws are a good approximation of the properties of physical space only when the gravitational field is weak. As a matter of fact, in the present cosmological model, the luminous portion of the Universe is expanding at a constant rate as in the de Sitter cosmology in a flat Universe; this is also the condition required in order for the model to match the luminosity distance versus redshift relationship of supernovae Ia. The dichotomous cosmology differs in the sense that it is the light wavelength that gets stretched due to a tired-light process and not space itself that expands.

The present model describes the dynamics of light using two transformations. First, we allow a time-varying light wavefront in order to accomodate the stretching of light's wavelength when photons lose energy. Second, a time dilation is incorporated into the model in order for the light wavefront to stay at the celerity of light. A consequence of this model is the "time-dilation effect" (a.k.a. the ageing of spectra) observed for supernovae light curves [8] with a stretching of the light curves by a factor $(1+z)$. In addition, the expanding luminous world is consistent with the radiation energy density factor $(1+z)^4$ inferred from the CMBR (Cosmic Microwave Background Radiation).

II. LIGHT AGEING MODEL

In the tired-light cosmology where redshifts are explained by a decay of the photon energy, the following equation replaces the cosmological redshift equation of the expanding Universe theory:

$$1 + z = \frac{\lambda_{obs}}{\lambda_{emit}} = \frac{E(z)}{E_0}\,, \qquad (1)$$

where λ_{obs} and λ_{emit} are the observed and emitted light wavelength respectively, E_0 the photon energy at reception, and $E(z)$ the photon energy when emitted at redshift z.

A simple law of decay of the photon energy is considered:

$$\frac{\dot{E}}{E} = -H\,, \qquad (2)$$

where E is the photon energy, and H the decay of photon energy. From now on we assume that the decay rate of photon energy is constant over time and is always equal to H_0.

By integrating (2) we get:

$$E(t) = E_0\,\exp(-H_0\,t)\,, \qquad (3)$$

where t is the time which is equal to zero time of observation, and E_0 the photon energy at reception.

Let us apply the following change of coordinates $T = t_0 - t$, where T is the light travel time when looking back in the past and t_o the present time. Hence, (3) can be rewritten as follows:

$$E(T) = E_0\,\exp(H_0\,T)\,, \qquad (4)$$

where T is the light travel time when looking back in the past from the earth.

It is shown below that a constant decay rate for the photon energy conforms to the supernovae luminosity distance versus redshift relationship.

III. LIGHT TRAVEL TIME WITH RESPECT TO THE POINT OF EMISSION AND LUMINOSITY DISTANCE

Here, we consider a set of two transformations to describe the photon energy decay. During this process the number of light wave cycles is constant, but due to the stretching of light wavelengths when photons lose energy we allow a superluminal light wavefront, resulting in an expansion. Then a time dilation is applied in order to maintain the speed of light at the celerity with respect to the emission point. The velocity of the light wavefront before time dilation is expressed as follows:

$$v(t) = c\frac{E_{emit}}{E(t)}\,, \tag{5}$$

where E_{emit} is the photon energy at emission, $E(t)$ the photon energy at time t, and c the celerity of light. We note that in (5) the light wavefront is at the speed of light at the point of emission.

In order to maintain the light wavefront at the speed of light with respect to the emission point, the following time dilation is applied:

$$\frac{\delta t'}{\delta t} = \frac{E_{emit}}{E(t)}\,, \tag{6}$$

where $\frac{\delta t\prime}{\delta t}$ is a time scale factor between time t' and time t.

The light travel time with respect to the point of emission is:

$$T' = \int_{-T}^{0} \frac{\delta t'}{\delta t} dt = \int_{-T}^{0} \frac{E_{emit}}{E(t)} dt\,, \tag{7}$$

where T' is the light travel time with respect to the point of emission, and T the light travel time with time-varying speed of light.

Introducing (3) into (7) we get:

$$T' = \frac{E_{emit}}{E_0} \int_{-T}^{0} \exp(H_0 t) dt\,. \tag{8}$$

Integrating (8) we obtain:

$$T' = \frac{E_{emit}}{E_0}\frac{1}{H_0}\left(1 - \exp(-H_0 T)\right)\,. \tag{9}$$

By substitution of (4) into (9), we get:

$$T' = \frac{E_{emit}}{E_0}\frac{1}{H_0}\left(1 - \frac{E_0}{E_{emit}}\right)\,. \tag{10}$$

Introducing (1) into (10) we get:

$$T' = \frac{z}{H_0}\,. \tag{11}$$

After the time dilation (6), the light wavefront is at the speed of light, hence the luminosity distance is expressed as follows:

$$\frac{dr_L}{dT'} = c\,. \tag{12}$$

By integrating (12) between 0 and T' we get the following equation:

$$r_L(T') = cT'\,. \tag{13}$$

By combining (11) and (13) we get the following relationship between luminosity distance and redshifts:

$$r_L = \frac{c}{H_0}\, z\,. \tag{14}$$

Ultimately, we find the linear relationship between luminosity distance and redshifts which is observed in supernovae Ia data. A rectilinear plot of the luminosity distance versus redshift of slope of 14.65 where the luminosity distance is expressed in *Gly* (billion light years) was obtained in [9] using the redshift adjusted distance modulus [10] which is based on photon flux. The corresponding decay rate of photon energy which is the inverse of the slope from (11) is equal to $H_0 = 2.16 \times 10^{-18}\, sec^{-1}$ or $67.3\, km\, s^{-1}\, Mpc^{-1}$.

To compute the luminosity distance, the light travel time with respect to the emission point must be used. In the luminosity distance the light wavefront is maintained at the speed of light with respect to the emission point where the time dilation is equal to unity. For an indication of distances of an object with respect to the observer, the light travel time with respect to the point of observation is used for which the time dilation is equal to unity.

IV. LIGHT TRAVEL TIME WITH RESPECT TO THE OBSERVER

The light travel time measured with respect to the observer is the light travel time obtained with a time dilation equal to unity at the point of observation. In this scenario, the velocity of the light wavefront before time dilation is as follows:

$$v(t) = c\frac{E_0}{E(t)}\,, \tag{15}$$

Thus, the time-dilation effect is:

$$\frac{\delta t_0}{\delta t} = \frac{E_0}{E(t)}\,, \tag{16}$$

where $\frac{\delta t_0}{\delta t}$ is a time scale factor between present time t_0 and time t.

Therefore, the light travel time with respect to the observer is:

$$T_0 = \int_{-T}^{0} \frac{\delta t_0}{\delta t} dt = \int_{-T}^{0} \frac{E_0}{E(t)} dt\,, \tag{17}$$

where T_0 is the light travel time with respect to the point of observation, and T the light travel time with time-varying speed of light.

Introducing (3) into (17) and integrating we get:

$$T_0 = \frac{1}{H_0}\left(1 - \exp(-H_0 T)\right)\,, \tag{18}$$

Introducing (4) into (18) we get:

$$T_0 = \frac{1}{H_0}\left(1 - \frac{E_0}{E_{emit}}\right)\,. \tag{19}$$

Finally, introducing (1) into (19):

$$T_0 = \frac{1}{H_0}\frac{z}{(1+z)}\,. \tag{20}$$

We note that in (20) when redshift tends to infinity, the light travel time with respect to the observer converges towards $1/H_0$. This is the farthest distance from which light can reach an observer in the Universe. There is a squeezing effect by the factor (1+z) for the light travel time when measured with respect to the point of observation instead of the point of emission. This squeezing of light travel time is due to the fact that time dilation is relative to the reference point in time from which the light wavefront is measured.

V. EQUIVALENCE IN THE DE SITTER COSMOLOGY FOR AN EXPANDING LUMINOUS WORLD

The de Sitter cosmology is dominated by a repulsive cosmological constant Λ which yields an expansion rate of the Universe H that does not vary over time.

In this cosmology, the luminosity distance is calculated as follows:

$$\frac{dr_L}{dt} = c + H\, r_L \tag{21}$$

with boundary condition $r_L = 0$ at $t = 0$. Where r_L is the luminosity distance, t the time at the light wavefront of the supernovae with reference to the emission time, and H the Hubble constant.

By integrating (21) between 0 and T, we get:

$$r_L = \frac{c}{H_0} \left(\exp(H\, T) - 1 \right) . \tag{22}$$

Because $\frac{da}{dt} = Ha$, we get $dt = \frac{da}{H\, a}$, where a is the scale factor. In addition, the cosmological redshift equation $(1 + z) = \frac{1}{a}$ establishes the relationship between z and a, hence the light travel time versus redshift is as follows:

$$T = \int_{1/(1+z)}^{1} \frac{da}{H\, a} = \frac{1}{H} \ln(1 + z) \,. \tag{23}$$

Eqs. (22) and (23) yield:

$$r_L = \frac{c}{H}\, z \,, \tag{24}$$

which is the same equation than (14).

A measure of distance is obtained by calculating the corresponding the distance if there were no expansion of the Universe, that we call the Euclidean distance. Let us introduce y this distance measure, hence:

$$\frac{dy}{dt} = -c + Hy \,. \tag{25}$$

By setting time zero at a reference T_b in the past, we get $t = T_b - T$; therefore, $dt = -dT$. Hence, (25) becomes:

$$\frac{dy}{dT} = c - Hy \,, \tag{26}$$

with boundary condition $y(T = 0) = 0$.

Integrating (26) between 0 and T we get:

$$y = \frac{c}{H} \left(1 - \exp(-HT)\right) . \tag{27}$$

By substitution of (23) into (27) we get:

$$y = \frac{c}{H} \frac{z}{(1 + z)} \,, \tag{28}$$

which is the same equation than (20) where $T_0 = \frac{y}{c}$.

We have shown that de Sitter expanding Universe is equivalent to a our light ageing model. In the de Sitter cosmology, the cosmological constant Λ corresponding to a positive vacuum energy density sets the expansion rate $H = \sqrt{\frac{1}{3}\Lambda}$, for a flat Universe, which is the photon energy decay rate of light traveling in vacuum.

VI. RADIATION DENSITY AND THE CMBR

The CMBR was a prediction of the work of George Gamow, Ralph Alpher, Hans Bethe and Robert Herman on the Big Bang nucleosynthesis [11, 12], and was discovered later in 1964 by Penzias and Wilson. It is believed that the CMBR is the remnant radiation of a primordial Universe made of plasma, and that galaxies are formed by gravitational collapse of this plasma phase. Here, we investigate a requirement for the CMBR to originate from a hot plasma.

From Wien's displacement law for thermal radiation from a black body, there is an inverse relationship between the wavelength of the peak of the emission spectrum and its temperature is expressed as follows:

$$\lambda_p T = b\,, \tag{29}$$

where λ_p is the peak wavelength and T the absolute temperature.

From this law we get:

$$\lambda_{obs} T_0 = \lambda_{emit} T_{emit}\,, \tag{30}$$

where T_0 is the temperature of the black body spectrum today, which is 2.7 K for the CMBR, and T_{emit} the temperature of the emitting plasma.

Hence:

$$T_{emit} = T_0 \frac{\lambda_{obs}}{\lambda_{emit}} = T_0(1+z)\,. \tag{31}$$

From the Stefan-Boltzmann's law, the energy flux radiating from a black body is as follows:

$$Flux = \sigma T^4\,, \tag{32}$$

where σ is the Stefan-Boltzmann constant, and T the temperature of the black body.

Combining (31) and (32), we find that the energy flux of the source of a black body that is redshifted is of order $(1+z)^4$. Hence, the energy flux of the emitting black body must be diluted by a factor $(1+z)^4$. For an expanding luminous phase, the photon flux is diluted by a factor $(1+z)^3$. Because photons lose energy as the light wavelength is stretched, another factor $(1+z)$ must be accounted for, and the resulting energy flux is diluted by a factor $(1+z)^4$. This is the required condition for the redshifted spectrum of a black body to be a black body spectrum itself. It appears that our cosmology with an expanding luminous world is consistent with the radiation energy density inferred from the CMBR.

VII. CONCLUSION

The dichotomous cosmology is inspired by the tired-light model and consists of a static material world and an expanding luminous world. In this model the luminous world is expanding at a constant rate as in de Sitter cosmology. The model consists of two transformations, respectively: (1) to compensate for the stretching of the light's wavelength when the photon loses energy, we allow a time-varying light wavefront; (2) a time-dilation effect is incorporated into the model in order for the light wavefront to stay at the speed of light. This model explains both the luminosity distance versus redshift relationship of supernovae Ia, and "time-dilation effect" observed with the stretching of supernovae light curves. Furthermore, it is consistent with a radiation energy density factor $(1 + z)^4$ inferred from the CMBR. This alternative cosmology only differs from the expanding Universe theory from the viewpoint that it is the light wavelength that is stretched due to a tired light process and not space itself that expands.

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