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SHORT COMMUNICATION

Non-adiabatic universe and the redshift

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ABSTRACT

We have relaxed the constraint of adiabatic universe used in most cosmological models and shown that the new approach provides a better fit to the supernovae Ia redshift data with a single parameter, the Hubble constant, than the standard ΛCDM model with two parameters, the Hubble constant and the cosmological constant. The new approach, developed within the confines of the cosmological principle, yields the Hubble constant value 69.01 (±0.53) km s^{-1} Mpc^{-1}. The cosmological constant may thus be considered as a manifestation of a non-adiabatic universe that is treated as an adiabatic universe.

***Keywords*:** Galaxies, Supernovae, Distances and redshifts, Cosmic microwave background radiation, Distance scale, Cosmology theory, Cosmological constant, Hubble constant, General relativity

1. INTRODUCTION

The redshift of the extragalactic objects, such as supernovae Ia (SNe Ia) is arguably the most important of all cosmic observations that are used for modeling the universe. Two major explanations of the redshift are the tired light effect in the steady state theory and the expansion of the universe [1]. However, since the discovery of the microwave background

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radiation by Penzias and Wilson in 1964 [2], the acceptable explanation for the redshift by mainstream cosmologist has steadily shifted in favour of the big-bang expansion of the universe, and today alternative approaches for explaining the redshift are not acceptable by most cosmologists. The situation has been most succinctly expressed by Vishwakarma and Narlikar in a recent paper [3] as follows: "… a recent trend in the analysis of SNeIa data departs from the standard practice of executing a quantitative assessment of a cosmological theory—the expected primary goal of the observations [4,5]. Instead of using the data to directly test the considered model, the new procedure tacitly assumes that the model gives a good fit to the data, and limits itself to estimating the confidence intervals for the parameters of the model and their internal errors. The important purpose of testing a cosmological theory is thereby vitiated."

Interestingly, it is the close analysis of the cosmic microwave background that has created tension between the Hubble constant derived from the spectral data and from the microwave background data [6, 7].

The status of the expanding universe and steady state theories has been recently reviewed by López-Corredoira [8] and Orlov and Raikov [9]. They concluded that based on the currently available observational data it is not possible to unambiguously identify the preferred approach to cosmology.

It was phenomenologically shown that the tired light may be due to Mach effect, which may contribute dominantly to the cosmological redshift [10]. While the paper's assumption that observed redshift may be a combination of the expansion of the universe and tired light effect appears to be sound, it incorrectly divided the distance modulus between the two components rather than keeping the proper distance the same and dividing the redshift. This was corrected in a subsequent paper [11] which showed that a hybrid of Einstein de Sitter cosmological model and the tired light (Mach effect) model gave an excellent fit to the SNe Ia data while at the same time providing analytically the deceleration parameter and the ratio of the contribution of the two models. Consequently, the new model was dubbed Einstein de Sitter Mach (EDSM) model.

Using Poisson's work on the motion of point particles in curved spacetime [12], Fischer [13] has shown analytically that gravitational back reaction may be responsible for the tired light phenomenon and could account for some or most of the observed redshift. His finding may also be related to Mach effect.

2. THEORY

The Friedmann equation, coupled with the fluid equation and the equation of state, provides the dynamics of the universe and thus the evolution of the scale factor a. It *does not* give the redshift z directly. The redshift is taken to represent the expansion, and only the expansion, of the universe, and thus scale factor is considered to be directly observable through the relation $a = 1/(1 + z)$. The relation ignores any other cause that may contribute to the redshift. If the redshift is indeed contributed partially by other factors, such as by the Mach effect, then the scale factor determined by said equations will not equate to $1/(1 + z)$. Unless the said equations are modified to take into account other factors, they cannot be considered to represent the cosmology correctly. Since energy density is common to all the three equations, and evolution of density is governed by the fluid equation, we will try to look at it with a magnifying glass. The starting point for the fluid equation in cosmology is the first law of thermodynamics [1,14]:

$$dQ = dE + dW, \tag{1}$$

where dQ is the thermal energy transfer into the system, dE is the change in the internal energy of the system, and $dW = PdV$ is the work done on the system having pressure P to increase its volume by dV. Normally, dQ is set to zero on the ground that the universe is perfectly homogeneous and that there can therefore be no bulk flow of thermal energy. However, if the energy loss of a particle, such as that of a photon through tired light phenomenon, is equally shared by all the particles of the universe (or by the 'fabric' of the universe) in the spirit of the Mach effect [15] then dQ can be non-zero while conserving the homogeneity of the universe.

We will thus abandon the assumption that $dQ = 0$. The first law of thermodynamics for the expanding universe then yields:

$$\dot{E} + P\dot{V} = \dot{Q}. \tag{2}$$

We now apply it to an expanding sphere of commoving radius r_s and scale factor $a(t)$. Then the sphere volume $V(t) = \frac{4\pi}{3} r_s^3 a(t)^3$, and

$$\dot{V} = V\left(\frac{3\dot{a}}{a}\right). \tag{3}$$

Since the internal energy of the sphere with energy density $\varepsilon(t)$ is $E(t) = \varepsilon(t)V(t)$, its rate of change may be written as

$$\dot{E} = V\dot{\varepsilon} + \dot{V}\varepsilon = V\left(\dot{\varepsilon} + \frac{3\dot{a}}{a}\varepsilon\right). \tag{4}$$

If we assume the energy loss $\dot{Q}$ to be proportional to the internal energy E of the sphere

$$\dot{Q} = -\beta E = -\beta\varepsilon V, \tag{5}$$

where β is the proportionality constant, then Equation (2) may be written as

$$\dot{\varepsilon} + \frac{3\dot{a}}{a}(\varepsilon + P) + \beta\varepsilon = 0, \tag{6}$$

which is the new fluid equation for the expanding universe. Using the equation of state relation $P = w\varepsilon$, and rearranging Equation (6), we may write

$$\frac{d\varepsilon}{\varepsilon} + 3(1 + w)\frac{da}{a} + \beta dt = 0. \tag{7}$$

Assuming w to be constant in the equation of state, this can be integrated to yield

$$\ln(\varepsilon) + 3(1+w)\ln(a) + \beta t + C = 0. \tag{8}$$

where C is the integration constant. Now $t = t_0$ corresponds to scale factor $a = 1$ and $\varepsilon = \varepsilon_0$, giving $C = -\ln(\varepsilon_0) - \beta t_0$. We may then write Equation (8) as

$$\varepsilon(a) = \varepsilon_0 a^{-3(1+w)} e^{\beta(t_0 - t)}. \tag{9}$$

Let us now examine the simplest form of the Friedmann equation (single component, flat universe) with G as the gravitational constant. It may be written [14] as

$$\left(\frac{\dot{a}}{a}\right)^2 = \left(\frac{8\pi G\varepsilon}{3c^2}\right). \tag{10}$$

Substituting ε from Equation (9), we get

$$\dot{a}^2 = \left(\frac{8\pi G\varepsilon_0}{3c^2}\right) a^{-(1+3w)} e^{\beta(t_0 - t)}. \tag{11}$$

Since $a_0 \equiv a(t_0) = 1$, it can be shown that it has the following solution:

$$a = a/a_0 = \left(\frac{1-e^{-\frac{\beta t}{2}}}{1-e^{-\frac{\beta t_0}{2}}}\right)^{\frac{2}{3+3w}}, \tag{12}$$

$$\approx \left(\frac{t}{t_0}\right)^{\frac{2}{3+3w}} \left(1 + \frac{1}{4}\beta\left(\frac{2}{3+3w}\right)(t_0 - t) + O(\beta^2)\right). \tag{13}$$

This reduces to the standard expression for the scale factor in adiabatic universe ($\beta = 0$). Since the Hubble parameter is defined as $H(t) = \dot{a}/a$, differentiating Equation (12) with respect to t and rearranging, we get

$$\frac{\dot{a}}{a} = \left(\frac{\beta}{3+3w}\right)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1}, \text{ or} \tag{14}$$

$$\mathrm{e}^{\frac{\beta t}{2}} = 1 + \left(\frac{1}{H(t)}\right)\left(\frac{\beta}{3+3w}\right), \text{ or} \tag{15}$$

$$\frac{\beta t}{2} = \ln\left(1 + \left(\frac{1}{H(t)}\right)\left(\frac{\beta}{3+3w}\right)\right), \text{ or} \tag{16}$$

$$t_0 = \frac{2}{3+3w}\left(\frac{1}{H_0}\right) \text{ when } \beta \Rightarrow 0. \tag{17}$$

Here Equations (15) and (16) can be used to determine the age of the universe in the non-adiabatic universe provided we know β. They reduce to Equation (17) in the limit of $\beta \Rightarrow 0$. It is the standard expression in adiabatic universe for the age of the universe in terms of the Hubble constant for a single component flat universe. We see from Equation (11) that at $t =$

t_0, $\dot{a}(t_0) = \sqrt{(\frac{8\pi G\varepsilon_0}{3c^2})}$. We can therefore write the expression for the age of the universe in terms the energy density as

$$t_{0,\beta} = \frac{2}{\beta}\ln\left(1 + \left(\frac{\beta}{2}\right)\left(\frac{1}{1+w}\right)\sqrt{\frac{c^2}{6\pi G\varepsilon_0}}\right), \text{ and} \tag{18}$$

$$t_{0,0} = \left(\frac{1}{1+w}\right)\sqrt{\frac{c^2}{6\pi G\varepsilon_0}} \text{ when} \Rightarrow 0\ . \tag{19}$$

Equation (18) is the expression for the age of the universe for the single component flat non-adiabatically expanding universe and Equation (19) is the standard expression for adiabatically expanding universe obtained in the limit of zero β.

We need to know β in order to get t_0 in the non-adiabatic universe. Since we know the analytically derived value of the deceleration parameter $q_0 = -0.4$ from the EDSM model [11], let us first workout the expression for the same from its standard definition

$$q_0 \equiv -\left(\frac{\ddot{a}a}{\dot{a}^2}\right)_{t=t_0}, \tag{20}$$

to see if β could be expressed in terms of H_0. Equation (14) may be differentiated and rearranged to obtain the expression for q_0 as follows.

$$\ddot{a}(t) = \left(\frac{\beta}{3+3w}\right)[\,\dot{a}(t)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1} - a(t)\left(e^{\frac{\beta t}{2}} - 1\right)^{-2} e^{\frac{\beta t}{2}}\left(\frac{\beta}{2}\right)], \tag{21}$$

$$= \left(\frac{\beta}{3+3w}\right)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1}\left[\dot{a}(t) - \left(\frac{\beta}{2}\right)a(t)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1} e^{\frac{\beta t}{2}}\right], \tag{22}$$

$$= \left(\frac{\dot{a}(t)}{a(t)}\right)\dot{a}(t)\left[1 - \left(\frac{\beta}{2}\right)\left(\frac{a(t)}{\dot{a}(t)}\right)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1} e^{\frac{\beta t}{2}}\right], \text{ or} \tag{23}$$

$$\frac{\ddot{a}(t)a(t)}{\dot{a}^2(t)} = 1 - \left(\frac{\beta}{2}\right)\left(\frac{a(t)}{\dot{a}(t)}\right)\left(e^{\frac{\beta t}{2}} - 1\right)^{-1} e^{\frac{\beta t}{2}}, \tag{24}$$

$$= 1 - \frac{3+3w}{2} e^{\frac{\beta t}{2}} \text{ from Equation (14), or} \tag{25}$$

$$q = -1 + \left(\frac{3(1+w)}{2}\right)e^{\frac{\beta t}{2}}, \text{ or } q_0 = -1 + \left(\frac{3(1+w)}{2}\right)e^{\frac{\beta t_0}{2}}. \tag{26}$$

for $q_0 = -0.4$ and $w = 0$, Equation (26) yields $e^{\frac{\beta t_0}{2}} = 0.4$ or $\beta = -1.833/t_0$. Substituting these values in Equation (15) at $t = t_0$ yields $\beta = -1.8H_0$ and the age of the universe $t_0 = 1.02H_0^{-1}$.

Up until now we have not used any observational data. In order to proceed further, we need to know the Hubble constant H_0. The observational data is usually provided in the form of distance modulus μ and the redshift z. In an expansion only model, we may write the distance modulus as [1,14]

$$\mu = 5\log(d_L) + 25, \text{ where} \tag{27}$$

$$d_L = (1+z)d_P, \text{ where} \tag{28}$$

$$d_P(t_0) = c\int_{t_e}^{t_0} \frac{dt}{a(t)}. \tag{29}$$

where d_L is the luminosity distance of the source emitting the photons at time t_e whose redshift is being measured, and d_P is the proper distance of the source in mega parsecs observed at time t_0. When all the redshift is allocated to the expansion of the universe, $1 + z = 1/a(t)$. We may then write Equation (29)

$$d_P(z) = c\int_{z(t_e)}^{z(t_0)} dz(1+z)/(\tfrac{dz}{dt}). \tag{30}$$

Equation (12) can now be used to determine dz/dt for substitution in Equation (30). Since we are observing redshift in the matter dominated universe, we may simplify Equation (12) by taking $w = 0$, and rewrite it as

$$1 + z = \frac{1}{a} = \left(1 - e^{-\frac{\beta t_0}{2}}\right)^{\frac{2}{3}}\left(1 - e^{-\frac{\beta t}{2}}\right)^{-\frac{2}{3}}, \text{ or} \tag{31}$$

$$\frac{dz}{dt} = \left(\frac{\beta}{3}\right)(1+z)\left(1 - e^{-\frac{\beta t}{2}}\right)^{-1}\left(-e^{-\frac{\beta t}{2}}\right). \tag{32}$$

We can use Equation (31) to express $\left(1 - e^{-\frac{\beta t}{2}}\right)^{-1}$ and $\left(-e^{-\frac{\beta t}{2}}\right)$ in terms of $1 + z$ and the constant term $\left(1 - e^{-\beta t_0}\right) \equiv A$,

$$\left(1 - e^{-\frac{\beta t}{2}}\right) = A/(1+z)^{\frac{3}{2}}, \tag{33}$$

and rewrite Equation (32) as

$$\frac{dz}{dt} = \left(\frac{\beta}{3}\right)[(1+z)^{\frac{5}{2}}/A]\left[\frac{A}{(1+z)^{\frac{3}{2}}} - 1\right], \text{ or} \tag{34}$$

$$= \left(\frac{\beta}{3}\right)(1+z)\left[1 - \frac{(1+z)^{\frac{3}{2}}}{A}\right]. \tag{35}$$

Equation (30) may now be written

$$d_P(z) = -\left(\frac{3c}{\beta}\right)\int_0^z du\left[1 - \frac{(1+u)^{\frac{3}{2}}}{A}\right]^{-1}. \tag{36}$$

There is no simple analytical solution for the integral in Equation (36). Substituting $A \equiv \left(1 - e^{-\beta t_0}\right) = -1.5$ and $\beta = -1.8H_0$ from above - Equation (26) and the paragraph following it, and defining $R_0 \equiv c/H_0$, we may write the distance modulus μ as

$$\mu = 5\log\left[\frac{R_0}{0.6}(1+z)\int_0^z du\left(1 + \left(\frac{2}{3}\right)(1+u)^{\frac{3}{2}}\right)^{-1}\right] + 25. \tag{37}$$

3. RESULTS

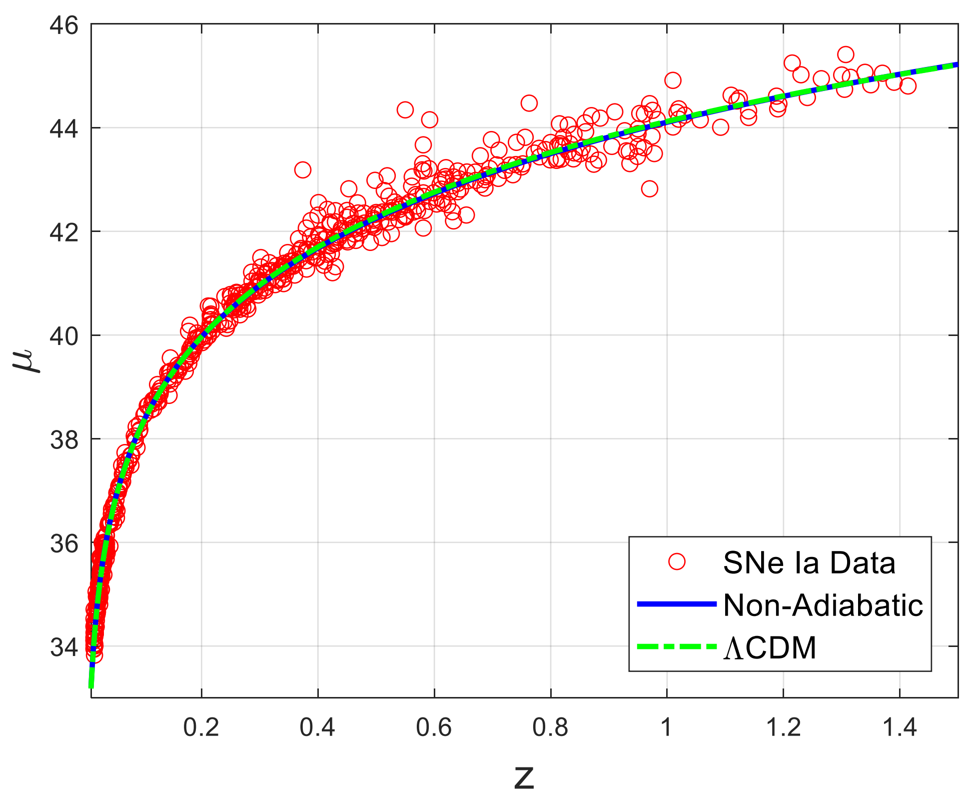

Figure 1. Fitted data curves for the two models in Table 1.

The database used in this study is for 580 SNe Ia data points with redshifts $0.015 \leq z \leq 1.414$ as compiled in the Union2 μ, z database [16] updated to 2017. We used Matlab curve fitting tool to fit the data using non-linear least square regression. To minimize the impact of large scatter of data points, we applied the 'Robust Bi-square' method. This tool fits data by minimizing the summed square of the residuals, and reduces the weight of outliers using bisquare weights. The Goodness of Fit is given by parameters SSE (sum of squares due to errors), R-Square and RMSE (root mean square error).

Figure 1 shows the curves fitted to the data set using Equation (37) and using standard ΛCDM model [11]. There is no visible difference between the two curves. Corresponding goodness-of-fit numbers are presented in Table 1. While it is not possible to assess better fit from the figure, the goodness-of-fit numbers clearly favour the non-adiabatic model, albeit only slightly. The result is unexpected as the fit for the non-adiabatic model is obtained using only one parameter, the Hubble constant, whereas the ΛCDM model requires two parameters.

Table 1. Parameter and goodness-of-fit for the two models.

Model	**Parameter**	95% Confidence		**Parameter**	95% Confidence		Goodness of Fit		
	H_0	H_0 Low	H_0 High	**Ω_m**	Ω_m Low	Ω_m High	SSE	R-Square	RMSE
ΛCDM Standard	**69.85**	70.71	69.01	**0.2877**	0.2489	0.3266	24.35	0.9959	0.2053
Non-Adiabatic	**69.01**	69.54	68.48	**None**	NA	NA	24.10	0.9959	0.2040

4. CONCLUSIONS

The cosmological model presented in this communication is based on relaxing the assumption that universe dynamics is adiabatic within the confines of the cosmological principle. The fact that a single parameter yields a better fit to the SNe Ia data using the non-adiabatic model presented herein than the two parameter fit of the same data using ΛCDM model establishes the superiority of the new model. The Hubble constant obtained by the two models is almost the same, in fact the new model gives little lower value, closer to that sought by cosmic microwave background data. It may therefore be possible to dispense with the cosmological constant after all, and corresponding perpetually elusive dark energy, as Einstein always wanted to correct his greatest mistake!

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