Research Article

Hubble Diagram Test of Expanding and Static Cosmological Models: The Case for a Slowly Expanding Flat Universe

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We present a new redshift (RS) versus photon travel time (t_s) test including 171 supernovae RS data points. We extended the Hubble diagram to a range of $z = 0.0141$ – 8.1 in the hope that at high RSs, the fitting of the calculated RS/ t_s diagrams to the observed RS data would, as predicted by different cosmological models, set constraints on alternative cosmological models. The Lambda cold dark matter (ΛCDM), the static universe model, and the case for a slowly expanding flat universe (SEU) are considered. We show that on the basis of the Hubble diagram test, the static and the slowly expanding models are favored.

1. Introduction

The basic premise of the big bang theory is that the universe is expanding. The velocity of expansion can be expressed by the linear relationship $v = cz = H_0 D_C$, where c is the velocity of light, z is the redshift (RS), D_C is the comoving proper distance of the emitting object, and H_0 is the Hubble constant [1].

Since one cannot measure the supposed universal expansion experimentally, different tests based on observational data have been proposed [2–4] to provide evidence for the expansion hypothesis. (i) The Tolman surface brightness test [5], (ii) the time dilation test, (iii) the cosmic microwave background (CMB) temperature as a function of the RS test, (iv) the apparent magnitude versus distance test, and (v) the angular size versus RS test were proposed as possible observational evidence for the expanding space supposition. Recently, López-Corredoira [6] critically reviewed the results of these tests and concluded that on the basis of previous tests, convincing evidence for the cosmic expansion hypothesis is still lacking. Over this, as pointed out by LaVioletta [7], Crawford [8], and López-Corredoira [9], the static universe model fits the observational data better than expansion models. At present, there is no decisive experimental proof in favor of or against the supposed universal expansion.

Recently, an early idea for testing the universal expansion, proposed by Sandage 1962 [10], by measuring the change of RS of galaxies owned to the deceleration rate of the expansion is gaining increasing interest (Steinmetz et al. [11]). The test, however, requires measurements of Doppler velocity drifts with an accuracy of $\sim 1 \text{ cm s}^{-1} \text{ yr}^{-1}$ which is not feasible at the present time, but new techniques for frequency measurements developed by Loeb [12] and Murphy et al. [13], for example, promise an effective means to prove or improve the expansion hypothesis in future experiments.

In this paper, we compare the observed Hubble diagram compiled from 171 supernovae RS data in the range of $z = 0.0141$ – 8.1 with theoretical Hubble diagrams calculated on the basis of the Lambda cold dark matter (ΛCDM) model, the static universe model, and the slowly expanding flat universe (SEU) model that expands according to (5) with $\Omega_M = 1$. We expect that in the high RS range, it should be possible to check more precisely whether the Hubble diagram follows a linear $z = H_0 D_C / c$ or the exponential

$$z = e^{H_0(d/c)} - 1 = e^{H_0 t_s} - 1 \quad (1)$$

relationship, an effect which is only slightly perceptible in the $z < 1$ region.

FIGURE 1: RS/ μ data, fitted with the logarithmic $\mu = 2.4761 \times \ln(z) + 44.198$ (dashed line) and the potential function $\mu = 44.102 \times z^{0.0593}$ (solid line).

2. Data Collection

In our analysis, we have included data obtained by Wei [14] from 59 calibrated high-RS gamma-ray bursts (GRBs) (Hymnium data set) from the 557 Union 2 compilation and 50 low RS GRBs and 62 gold-set data [15]. Because the RS/magnitude data are plagued by considerable scatter, the best-fit curve was used to perform a global fitting over the RS range of $z = 0.0141$ – 8.1 .

2.1. Best-Fit Curves of the Observed RS/ μ Data. Best-fit curves were computed with Excel using the logarithmic $\mu = a \times \ln(z) + b$ and the potential $\mu = a \times z^b$ functions. Fitting the data with exponential and polynomial functions was not successful. The goodness of the fits was characterized by the corresponding R -square and χ -square values.

Results are shown in Figure 1.

The best-fit curves are represented by

$$\mu = 2.4761 \pm 0.06 \times \ln(z) + 44.198 \pm 0.079, \quad R^2 = 0.9479, \quad \sum_{i=1}^{171} \chi_i^2 = 1.892, \quad (2)$$

$$\mu = 44.102 \pm 0.032 \times z^{0.0593 \pm 0.00066}, \quad R^2 = 0.9571, \quad \sum_{i=1}^{171} \chi_i^2 = 1.6923. \quad (3)$$

Although the potential fit shows a somewhat better regression coefficient R^2 and a slightly better $\sum \chi^2$ on the basis of these small differences between the goodness of fit indicators, neither of the two functions can be excluded from further consideration. The differences between the two

TABLE 1: RS/ t_s data calculated with (2), (3), and (4).

RS (z)	μ	$t_s \times 10^{-14}$, sec.	
		(2)	(3)
0.5	42.326	2150	2001
1.0	44.102	3554	3400
1.5	45.1752	4514	4459
2.0	45.952	5222	5314
2.5	46.5646	5773	6039
3.0	47.0708	6219	6672
3.5	47.5030	6590	7236
4.0	47.8807	6907	7750
4.5	48.2163	7182	8230
5.0	48.5185	7423	8663
5.5	48.7935	7639	9076
6.0	49.0459	7833	9467
6.5	49.2792	8010	9838
7.0	49.4963	8171	10193
7.5	49.6992	8320	10533
8.0	49.8898	8458	10860

trend lines become more pronounced only in the RS/ t_s data representation.

The photon flight time t_s was calculated from

$$t_s = \frac{D_C}{c} = \frac{10^{(\mu+5)/5}}{(z+1) \times 3 \times 10^{10}} \times 3.085 \times 10^{18}. \quad (4)$$

Using (2), (3), and (4), the RS/ μ data were converted into RS/ t_s data sets.

Results are shown as RS/ $t_s \times 10^{-14}$ data.

The calculated μ/t_s data are summarized in Table 1.

Precision in determination of $D_C(t_s)$ is given by the error limits which are shown in (2) and (3). Figure 5 shows a graphical illustration of measurement error for the upper and lower limits of t_s inferred for the potential best fit function. The interpretation of this diagram for constraining the different cosmological models is discussed in detail in Section 3.2.

In Table 1, t_s means the flight time of the photons from distance D_C to the observer that should not be confused with the photon travel time (t) in a universe expanding according to the Λ CDM model. The Λ CDM model with $H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.266$, $\Omega_\Lambda = 0.732$, and $k = 0$, for example, leads to a mathematically correct solution for the evolution of an expanding universe; the universe has expanded from its beginning to the present time to an extent of about $D_C = 46$ billion light years. However, the Λ CDM model, though cosmologically important, has by itself no physical basis and requires a choice of free parameters (DM and DE) in order to fit the underlying expansion theory to the observed RS/d data.

We consider the case that although the result obtained on the basis of the Λ CDM model is a mathematically correct description of the present distances in an expanding universe, nevertheless, the expanding space interpretation is fictitious, and the universe may be static, or slowly expanding, and

FIGURE 2: Logarithmic best-fit curve (solid line), Λ CDM with $H_0 = 77.25 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (dashed line), and tired light model with $H_0 = 2.35 \times 10^{-18} \text{ Hz s}^{-1} \text{ Hz}^{-1}$ (dot-dashed line).

infinite, or very large, in extent. In this case, the Λ CDM model represents only a mathematical fit to the observed RS data, but in reality, the calculated distances represent nonexpanding distances between the observer and the emitting objects in a static universe. On this assumption, the flight time of photons between emission and reception is $t_s = D_C/c$, which is proportional to the D_C that goes into the linear Hubble law.

3. Results

The performance of the three model cosmologies, the Λ CDM, tired light, and SEU models, is compared with the observational RS/ t_s data base, each of which makes different predictions about the relation between t_s (D_C/c) and z .

3.1. Evaluation of the Logarithmic Best-Fit Results. In Figure 2, the RS/ t_s data calculated on the basis of the Λ CDM model with $H_0 = 77.25 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and the tired light model with $H_0 = 2.35 \times 10^{-18} \text{ Hz s}^{-1} \text{ Hz}^{-1}$ are compared with the logarithmic fit data.

As can be seen from Figure 2, the calculated data depart significantly from the best-fit curve, for $z < 3$ to the left and for $z > 3$ to the right side of the solid line. Over this, the value of the Hubble constant of $\sim 77.25 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is, compared with novel RS data, too high and does not fit the gold-set RS data which is the most accurate RS compilation presently known (Figure 3).

3.2. Evaluation of the Potential Best-Fit Results. Results are shown in Figures 4 and 5.

The most impressive result of our test is that the RS/ t_s relation obtained from the potential best-fit data (solid line) can be expressed nearly exactly by the exponential formula $z = e^{2.05 \times 10^{-18} t_s} - 1$ (diamonds) over the whole range of z with a statistical significance of $P_{\chi\text{-square}} = 0.8347$. Also, the slowly expanding universe model (crosses) with $H_0 = 2.017 \times 10^{-18} \text{ Hz s}^{-1} \text{ Hz}^{-1}$ plus the RS resulting from the expansion with $5 \text{ km s}^{-1} \text{ Mpc}^{-1}$ shows a similarly good fit with $P_{\chi\text{-square}} = 0.4734$, and consequently the two models become nearly identical.

FIGURE 3: Triangles: gold-set data; solid line: $H_0 = 77.25 \text{ km s}^{-1} \text{ Mpc}^{-1}$; dashed line: $H_0 = 66 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

FIGURE 4: Redshift of Type Ia supernovae as a function of $t_s = D_C/c$. Solid line: RS/ t_s relation inferred from the potential best-fit curve of the RS/ μ diagram. Diamonds: the potential relation with $H_0 = 2.05 \times 10^{-18} \text{ Hz s}^{-1} \text{ Hz}^{-1}$. Crosses: RS for the SEU with $H_0 = 2.017 \text{ Hz s}^{-1} \text{ Hz}^{-1} + \text{RS}$ resulting from expansion with $5 \text{ km s}^{-1} \text{ Mpc}^{-1}$. Dashed line: RS/ t_s relation derived from the distances D_C obtained from the Λ CDM model with $H_0 = 66 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

The dashed line in Figure 4 stands for the RS/ t_s relation, derived from the distances D_C obtained from the Λ CDM model with $H_0 = 66 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.266$, $\Omega_\Lambda = 0.732$, and $k = 0$ [16].

Figure 5 shows the error limits of the potential trend line together with the calculated RS data of the Λ CDM model.

One can see from Figure 5 that the RSs calculated on the basis of the Λ CDM model (diamonds) show a poor agreement with the observed data. Many data points lie outside of the error boundaries and show a systematic (nonstatistical) deviation from the best-fit line. The χ -square test leads to a statistical significance between the observational potential fit and the calculated Λ CDM data of $P = 0$. On the basis of this analysis, the Λ CDM model can be omitted.

FIGURE 5: Potential best-fit function (solid line), upper and lower limits due to measurement error (dashed lines), and Λ CDM model (diamonds).

The Hubble diagram clearly follows the exponential tired light RS formula as expected for static and for slowly expanding universe models.

4. The Slowly Expanding Universe

When GR is applied to the universe as a whole, it turns out that space should either be contracting or expanding. On the assumption that expansion is governed by the gravitational attraction of the observable mass density $\rho_{M,obs.}$ against the outward impulse of motion, the solution of the field equation ($k = 0$; $\Lambda = 0$) leads to

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3} \rho_{M,obs.} \quad (5)$$

Surprisingly, this simple model that naturally follows from the Einstein equation and from the observable mass density was not considered in the literature as a possible alternative to the static and the big bang models at all, although when it is compared with the Λ CDM and static universe models, its advantages is obvious. For example, consider the following.

- (i) Inferring the Hubble constant from the observable mass density of some $10^{-31} \text{ g cm}^{-3}$ (instead of $\sim 10^{-29} \text{ g cm}^{-3}$ as calculated on the basis of the still controversial interpretation of RS as recession velocity) leads to $H_0 = \sqrt{(\rho_{obs.} \times 8\pi G)/3} \sim 5\text{--}15 \text{ km s}^{-1} \text{ Mpc}^{-1}$, and the missing mass problem on the cosmic scale does not arise.
- (ii) Inferring the age of the universe from $1/H_0$ with $H_0 \sim 10 \text{ km s}^{-1} \text{ Mpc}^{-1}$ yields ~ 100 billion years, and with this, galaxies may have been evolved over time in some regular way without the need for DM or DE.
- (iii) In comparison with the Λ CDM and static universe models, the SEU model is simple and follows from GR without additional free parameters like the elusive dark components DM and DE or, in case of a static universe, the cosmological constant Λ of unknown physical nature.

- (iv) SEU is exclusively based on observable quantities, that is $\rho_{M,obs.}$, the experimentally measured RS distance relation, and the experimentally confirmed Euclidean geometry of the universe, instead of introducing unknown particles and energy.

5. The Redshift Problem

The interpretation of RS of atomic spectral lines suffers from the fact that none of the proposed mechanisms—the expanding space paradigm or the different tired light mechanisms—can be verified experimentally. Thus, the confidence in each theory must be measured by its success in explaining the observational phenomena. In Section 3, we have shown that observed RS date agree well with data inferred from (1), characteristic of tired light energy depletion.

According to SEU, the RS of the spectral lines is composed of a velocity $H_{0,expansion}$ and a superimposed RS $H_{0,tired-light}$ component of as yet unknown origin, and the rate of expansion is much lower than suggested by the accepted value of the Hubble constant of $H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$. The universe expands according to the Friedmann equation with $\rho_{M,obs.} \approx 10^{-31} \text{ g cm}^{-3}$, $\Lambda = 0$, and $k = 0$.

Our results support the assumption that the major part of RS is due to some tired light mechanism. According to this interpretation, H_0 does not represent the velocity of expansion, $\text{km s}^{-1} \text{ Mpc}^{-1}$, but it is as an additional term for the rate of energy loss from starlight due to some tired light mechanism which has the dimension $\text{Hz s}^{-1} \text{ Hz}^{-1}$.

The tired light scenario assumes that a photon loses energy due to some unknown process when it travels through space. The idea was first suggested by Zwicky [17] as a phenomenological approach to explain the Hubble relation. The major problem with this theory is the identification of a convincing physical process responsible for the observed loss of energy. There is no known interaction that can degrade a photon's energy without also changing its momentum, which would lead to a blurring of distant objects which is not observed. With these objections, the tired light RS theory was discarded.

Since that time, however, several mechanisms have been proposed that avoid blurring and scattering [18–20]. A reconsideration of the tired light model in context of these theories appears to be warranted.

Therefore, although the explicit physical nature of the energy loss of photons in transit is still a matter of debate, this lack of knowledge cannot be used as a decisive argument against the tired light theories. The cosmologically more important issue was to decide whether the Hubble diagrams follow a linear or exponential relationship. The presented RS/ t_s test clearly favors the static and the SEU models.

6. Conclusions

We have discussed here the Hubble diagram test for expanding and static universe models and show that the exponential energy depletion $z = e^{H_0 t_s} - 1$, characteristic for static and

also for slowly expanding universe models, fits the experimental data with high accuracy, while the RSs calculated on the basis of the Λ CDM model are in poor agreement with observation.

We have shown that the slowly expanding universe model unifies the advantages of expanding and static models by avoiding their problems, namely, the DM, DE problem of the Λ CDM model, and, in case of the static universe, the problem of the cosmological constant and gravitational instability.

On the basis of the results presented in this paper, we feel that the SEU model represents a promising alternative to the Λ CDM and static universe models that possibly could be verified by studying the effect of the lower expansion rate on the big bang nucleosynthesis (BBN). It is known that the relic abundance of the light elements depends on the expansion rate which determines the temperature and nucleon density in the early universe which in turn has a strong influence on the elements abundance pattern. As a consequence, BBN could set further constraints on the discussed cosmological models.

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