Modelling and Analysis of the Hubble Diagram of 280 Type SNIa Supernovae and Gamma Ray Bursts Redshifts with Analytical and Empirical Redshift/Magnitude Functions

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Abstract

Based on an analysis of 280 Type SNIa supernovae and gamma-ray bursts redshifts in the range of \(z = 0.0104 - 8.1\) the Hubble diagram is shown to follow a strictly exponential slope predicting an exponentially expanding or static universe. At redshifts > 2 - 3 \(\Lambda\)CDM models show a poor agreement with the observed data. Based on the results presented in this paper, the Hubble diagram test does not necessarily support the idea of expansion according to the big-bang concordance model.

Keywords
Magnitude, Redshift Data Fitting, Supernovae, Gamma Ray Bursts, Hubble Diagram, \(\Lambda\)CDM Cosmological Model

1. Introduction

Based on an analysis of 280 Type SNIa supernovae and gamma ray bursts redshift (\(z\)) data Marosi [1] has shown that the best-fit function to represent the observational \(z/\mu\) data set is the exponential equation 

\[
\mu = 44.109769 \times z^{0.059883}
\]

Recently, a number of papers have appeared proposing different analytical formulae for describing the experimental \(z/\mu\) relationship: Sorrell [2], Vigoureux, Vigoureux and Langlois [3] Traunmüller [4] and Churoux [5]. In this paper, observed \(z/\mu\) data of 280 Type SNIa supernovae and...
gamma ray bursts in the range of $z = 0.0104 - 8.1$ are compared to results calculated on the basis of these theoretically derived and empirical functions and the Lambda cold dark matter ($\Lambda$CDM) model. The aim of this paper is to examine which of the above functions and models fits the observations more accurately. We expect that in the high RS range it should be possible to decide whether the Hubble diagram follows the distance/$z$ relationship as predicted by the $\Lambda$CDM model, or the exponential tired light formula.

2. Data Collection and Processing

The $z/\mu$ data set consists of 171 gold-set data, Riess et al. [6], and 109 cosmology independent calibrated gamma-ray bursts (GRB) data consisting of 59 high-RS data (Hymnium data set) and 50 low RS GRBs obtained by Wei [7] from the 557 Union 2-compilation.

The following mathematical functions and cosmological models were used to perform a global fitting over the RS range of $z = 0.0104 - 8.1$.

\[
\mu = 44.109 e^{0.059844} (Marosi, 2014) \tag{1}
\]
\[
\mu = 25 + 5 \log(c/H_0) + 5 \log((z+1)\ln(z+1)) \quad (Vigoureux \ et \ al., \ 2014) \tag{2}
\]
\[
\mu = 2.5 \log\left((z+1) \frac{c^2}{H_0^2} z^2 \right) \quad (Churoux, \ 2015) \tag{3}
\]
\[
\text{\$\Lambda$CDM model with } H_0 = 62.5 \text{ km s}^{-1} \text{ Mpc}^{-1}, \ \Omega_m = 0.286, \ \Omega_\Lambda = 0.732 \text{ and } k = 0 \tag{4}
\]
\[
\text{\$\Lambda$CDM model with } H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}, \ \Omega_m = 0.286, \ \Omega_\Lambda = 0.732 \text{ and } k = 0 \tag{5}
\]

The $\mu$ values on basis of the $\Lambda$CDM models were calculated using:

\[
\mu = -5 + 5 \log D_L, \tag{6}
\]

where $D_L$ (Pc) is the luminosity distance. The luminosity distances were calculated using the cosmological calculator described by Wright [8].

For preparing the linear $t_s/z$ Hubble diagram, using Equation (7) the fitted $z/\mu$ data were converted into the corresponding $t_s/z$ datasets.

The photon flight-time $t_s$ was calculated using:

\[
t_s = \frac{D_L}{c} = \frac{10^{\mu+5}}{5} \times 3 \times 10^{10} \times 3.085 \times 10^{18} \tag{7}
\]

In Equation (7) $t_s$ means the flight time of the photons (sec.) from the co-moving radial distance $D_L$ to the observer, $t_s = D_L/c$, which is proportional to the $D_L$ (Pc) that goes into the linear Hubble law.

In order to complete the fitted $z/\mu$ data set in the high RS range of $t_s \times 10^{14} = 6000 - 11000$, in addition to the measured RSs, using Equation (2), 41 equidistant $t_s/z$ data points were included into the Hubble diagram. The addition of the 41 additional data points is necessary to perform the $\sum \chi^2$-test between the best fit and the $\Lambda$CDM models because only few observations are available in this redshift range. The $t_s/RS$ values were calculated on the basis of Functions (2) and (5).

Excel and Excel Solver were used for data fitting, refinement, and data presentation.

3. Results

Figure 1 shows results of the $z/\mu$ data fitting with Functions (1)-(5).

It is easy to see by visual examination of Figure 1 that there are only minor differences between the fit curves calculated with Functions (1) and (2), whilst the $\Lambda$CDM model with $H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (bottom line in Figure 1) is slightly but perceptibly different.

The most reliable measure to quantify the differences between the individual fit curves turned out to be the $\sum \chi^2$-test. The goodness of fit indicators are shown in Table 1.

The $\sum \chi^2$-test obviously favors the trend-lines obtained with Functions (1) and (2) and these two curves are practically congruent. On basis of the data presented in Table 1 the analytical best-fit Function (2) will be used as the best representation of the observed $z/\mu$ data in the following discussion.

Figure 2(a) and Figure 2(b) show Hubble diagrams calculated on basis of the Functions (2), (4) and (5).
Figure 1. Squares: observed $z/\mu$ data; long dash-dot line: (2); solid line: (1); dash-dot line: (3); long dashed line: $\Lambda$CDM, $H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$; short dashed line: $\Lambda$CDM, $H_0 = 62.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

### Table 1. Goodness of fit indicators of the $z/\mu$ data trend-lines.

<table>
<thead>
<tr>
<th>Function (F)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum \chi^2_{\mu,\text{obs}}/\text{F(1 - 5)}$</td>
<td>1.958865</td>
<td>1.96555</td>
<td>2.38869</td>
<td>2.163105</td>
<td>2.1582</td>
</tr>
<tr>
<td>$\sum \chi^2_{\text{F2-F(1; 3 - 5)}}$ %</td>
<td>-0.34</td>
<td>-</td>
<td>17.78</td>
<td>9.57</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Figure 2. (a) Redshift of type Ia supernovae as a function of $t_\delta = D/c$. Squares (dashed line): $t_\delta/z$ data inferred from the potential best-fit curve of the observed $z/\mu$ diagram. Triangles: $t_\delta/z$ relationship derived from the $\Lambda$CDM model with $H_0 = 72.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$, Circles: $t_\delta/z$ relationship derived from the $\Lambda$CDM model with $H_0 = 62.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$; (b) squares: $t_\delta/z$ data inferred from the potential best-fit curve of the observed $z/\mu$ diagram, solid line: exponential trend-line (Excel).

### 4. Discussion

The most important result of the Hubble diagram test is that fitting the $t_\delta/z$ data with Function (2) and $H_0 = 62.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (dashed line in Figure 2(a)) leads exactly to the exponential function:

$$Z + 1 = e^{2.0310^{-18} t_\delta}$$

as illustrated in Figure 2(b).

In spite of numerous correction factors and unknown constituents, dark matter (DM) and dark energy (DE), the $\Lambda$CDM models show a poor agreement with the observed data: as shown in Figure 2(a) the $\Lambda$CDM model with $H_0 = 62.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$ departs from the best-fit curve for $z + 1 < 6.5$ to the bottom, for $z + 1 > 6.5$ to the upper side of the trend-line. The deviations are of a systematic (nonstatistical) nature and, therefore, the model cannot reflect the observational exponential slope.
In the range of \( z > 3 \) the \( \Lambda \)CDM model with \( H_0 = 72.6 \text{ km s}^{-1} \text{Mpc}^{-1} \) shows a sharp increase in slope and departs considerably from the observed exponential function. For performing the \( \sum \chi^2 \)-test in the high RS range of \( t_S \times 10^{-14} = 6000 - 11000 \) (Figure 3), using Equation (2), 41 calculated \( t_S/z \) data points were included into the Hubble diagram. The \( \sum \chi^2 \)-test leads to a statistical significance between the observed \( t_S/\mu \) and the calculated \( \Lambda \)CDM data of \( P = 0.053 \), indicating that from the statistical point of view, the two models are essentially different.

5. Conclusions

The results presented in this paper have demonstrated that the \( \Lambda \)CDM-model cannot fit the strictly exponential slope of the Hubble diagram in the entire RS range of \( z = 0.0104 - 8.1 \), showing that the underlying theory is, at best, incomplete. A reconsideration of the \( \Lambda \)CDM-model appears warranted.

The Hubble diagram test leads to the significant conclusion that either: (1) the universe expanded exponentially during the whole time of its expansion history (at least in the range of \( z = 0.0104 - 8.1 \)); or (2) the universe is static and the RS of spectral lines is caused by some as-yet unidentified mechanism. However, both of these models, the exponentially expanding and the static universe models have their own crucial problems; the discussion of them is not within the scope of this paper.

References


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