Available online at www.sciencedirect.com
ScienceDirect
Physics Letters B 654 (2007) 139–147
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Interacting energy components and observational $H(z)$ data

Hao Wei [a,*], Shuang Nan Zhang [a,b,c]

[a] Department of Physics and Tsinghua Center for Astrophysics, Tsinghua University, Beijing 100084, China
[b] Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[c] Physics Department, University of Alabama in Huntsville, Huntsville, AL 35899, USA

Received 30 April 2007; received in revised form 8 August 2007; accepted 21 August 2007

Available online 1 September 2007

Editor: M. Cvetič

Abstract

In this Letter, we extend our previous work [H. Wei, S.N. Zhang, Phys. Lett. B 644 (2007) 7, astro-ph/0609597], and compare eleven interacting dark energy models with different couplings to the observational $H(z)$ data. However, none of these models is better than the simplest ΛCDM model. This implies that either more exotic couplings are needed in the cosmological models with interaction between dark energy and dust matter, or *there is no interaction at all*. We consider that this result is disadvantageous to the interacting dark energy models studied extensively in the literature.

PACS: 95.36.+x; 98.80.Es; 98.80.-k

1. Introduction

Nowadays, dark energy study has been one of the most active fields in modern cosmology [1], since the discovery of the present accelerated expansion of our universe [2–7]. In the past years, many cosmological models are proposed to interpret this phenomenon. One of the important tasks is to confront them with observational data. The most frequent method to constrain the model parameters is fitting them to the luminosity distance

$$d_L(z) = (1+z)\int_0^z \frac{d\tilde{z}}{H(\tilde{z})}, \tag{1}$$

which is an integral of Hubble parameter $H \equiv \dot{a}/a$, where $a = (1+z)^{-1}$ is the scale factor (z is the redshift); a dot denotes the derivative with respect to cosmic time t. However, the integral cannot take the fine structure of $H(z)$ into consideration and then lose some important information compiled in it (this point is also noticed in, e.g., [8]). Therefore, it is more rewarding to investigate the observational $H(z)$ data directly.

The observational $H(z)$ data we used here are based on differential ages of the oldest galaxies [9]. In [10], Jimenez et al. obtained an independent estimate for the Hubble constant by the method developed in [9], and used it to constrain the equation-of-state parameter (EoS) of dark energy. The Hubble parameter depends on the differential age as a function of redshift z in the form

$$H(z) = -\frac{1}{1+z}\frac{dz}{dt}. \tag{2}$$

Therefore, a determination of dz/dt directly measures $H(z)$ [11]. By using the differential ages of passively evolving galaxies determined from the Gemini Deep Deep Survey (GDDS) [12] and archival data [13], Simon et al. determined $H(z)$ in the range $0 \lesssim z \lesssim 1.8$ [11]. The observational $H(z)$ data from [11] are given in Table 1 and shown in Figs. 2–5.

These observational $H(z)$ data have been used to constrain the dark energy potential and its redshift dependence by Simon et al. in [11]. Yi and Zhang used them to constrain the parameters of holographic dark energy model in [16]. In [14], Samushia and Ratra have used these observational $H(z)$ data to

* Corresponding author.
E-mail address: haowei@mail.tsinghua.edu.cn (H. Wei).

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2007.08.056

Table 1
The observational $H(z)$ data [10,11] (see [14,15] also)

z	0.09	0.17	0.27	0.40	0.88	1.30	1.43	1.53	1.75
$H(z)$ ($\mathrm{km\,s^{-1}\,Mpc^{-1}}$)	69	83	70	87	117	168	177	140	202
1σ uncertainty	±12	±8.3	±14	±17.4	±23.4	±13.4	±14.2	±14	±40.4

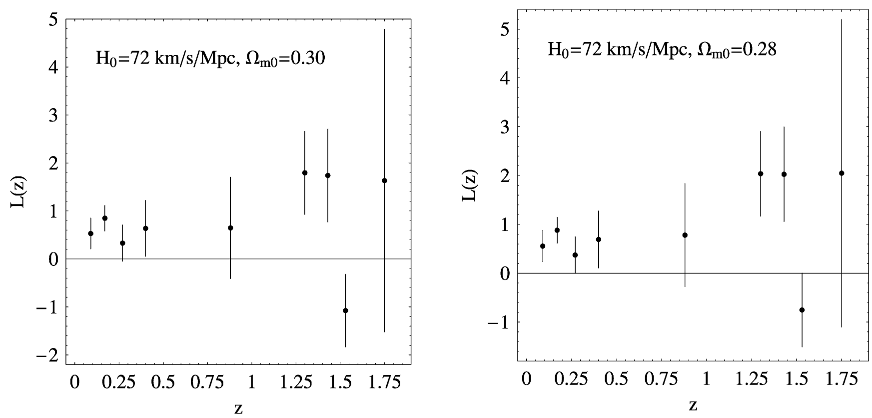

Fig. 1. The quantity $L(z) \equiv H^2(z)/H_0^2 - \Omega_{m0}(1+z)^3$ versus redshift z, for the fiducial parameters $H_0 = 72\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $\Omega_{m0} = 0.3$ (left panel) or 0.28 (right panel).

constrain the parameters of ΛCDM, XCDM and ϕCDM models. Some relevant works also include [8,15–20] for examples.

By looking carefully on the observational $H(z)$ data given in Table 1 and shown in Figs. 2–5, we notice that two data points near $z \sim 1.5$ and 0.3 are very special. They deviate from the main trend and dip sharply, especially the one near $z \sim 1.5$; the $H(z)$ decreases and then increases around them. This hints that the effective EoS crossed -1 there. In our previous work [15], we have confronted ten cosmological models with observational $H(z)$ data, and found that the best models have an oscillating feature for both $H(z)$ and effective EoS, with the effective EoS crossing -1 around redshift $z \sim 1.5$, while other non-oscillating dark energy models (e.g., ΛCDM, XCDM, vector-like dark energy etc.) cannot catch the main feature of the observational $H(z)$ data.

In Fig. 1, we show the quantity $L(z) \equiv H^2(z)/H_0^2 - \Omega_{m0}(1+z)^3$ versus redshift z, which is associated with the fractional energy density of dark energy, for the fiducial parameters $H_0 = 72\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $\Omega_{m0} = 0.3$ or 0.28, where the subscript "0" indicates the present value of the corresponding quantity. It is easy to see that the fractional energy density of dark energy of the point near $z \sim 1.5$ is negative (beyond 1σ significance). To avoid this, one can decrease the corresponding Ω_{m0} or make the matter decrease with the expansion of our universe slower than a^{-3}. Inspired by this, it is natural to consider the possibility of exchanging energy between dark energy and dust matter through interaction. In fact, we considered the cases with constant coupling coefficient in [15]. However, we found that it is not preferred by the observational $H(z)$ data. In the present work, we will explore more forms of couplings between dark energy and dust matter, in an attempt to find the couplings which can best describe the observational $H(z)$ data.

As extensively considered in the literature (see, e.g., [21–33,35,36,39–43]), we assume that dark energy and dust matter exchange energy through interaction according to

$$\dot{\rho}_X + 3H(\rho_X + p_X) = -3QH\rho_m, \tag{3}$$

$$\dot{\rho}_m + 3H\rho_m = 3QH\rho_m, \tag{4}$$

which preserves the total energy conservation equation $\dot{\rho}_{\rm tot} + 3H(\rho_{\rm tot} + p_{\rm tot}) = 0$. We assume that the EoS of dark energy $w_X \equiv p_X/\rho_X$ is constant, and consider a spatially flat Friedmann–Robertson–Walker (FRW) universe throughout this work. Notice that the coupling coefficient $Q = Q(z)$ can be any function of redshift z. So, the interaction term $3QH\rho_m$ is a general form, in contrast to the first glance. Integrating Eq. (4), it is easy to get

$$\rho_m \propto \exp\left[\int 3(Q-1)\,dN\right], \tag{5}$$

where $N \equiv \ln a = -\ln(1+z)$ is the so-called e-folding time; the constant proportional coefficient can be determined by requiring $\rho_m(N=0) = \rho_{m0}$. Then, ρ_X can be also obtained by substituting ρ_m into Eq. (3). From the Friedmann equation $3H^2 = 8\pi G(\rho_m + \rho_X)$, the Hubble parameter is in hand.

In the following sections, we will compare the observational $H(z)$ data with some cosmological models with different couplings. We adopt the prior $H_0 = 72\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, which is exactly the median value of the result from the Hubble Space Telescope (HST) key project [34], and is also well consistent with the one from WMAP 3-year result [4]. Since there are only 9 observational $H(z)$ data points and their errors are fairly large, they cannot severely constrain model parameters alone. We perform a χ^2 analysis and compare the cosmological models to find out the one which catches the main features of the observational $H(z)$ data. We determine the best-fit values for the model parameters by minimizing