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Dark energy cosmological models with H(z) and SNIa data

Altimare Maíres Ribeiro[∗†]
Universidade Federal de Itajubá
E-mail: altimare2006@hotmail.com

Armando Bernui
Universidade Federal de Itajubá
E-mail: abernui@gmail.com

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[∗]Speaker.
[†]FAPEMIG

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1. Introduction

The current observations with type Ia supernovae (SNIa) indicate that the universe is accelerating [1, 2]. In the context of General Relativity the universe today is dominated by a mysterious substance called dark energy, responsible for the current accelerated expansion [3, 4].

Various theoretical dark energy models have been proposed. We start with the ΛCDM model. This model assume that the constant dark energy density, Λ, a homogeneous fluid with equation of the state parameter $\omega_\Lambda = p_\Lambda/\rho_\Lambda = -1$, where p_Λ and ρ_Λ are the fluid pressure and energy density, respectiviely. The ΛCDM model provides an excellent fit with observational data. Despite its success, the ΛCDM model is not definitive. The principal problem is the difference between the observed value of Λ and the expectation theoretical. Others cosmological models have been proposed to solve this problem. Examples include models with constant equation of state $\omega < -1$ know as ωCDM and the Chevallier-Polarski-Linder (CPL) parametrization with ω_a proportional to $1+\omega_0$, $\omega(a) = \omega_0 + \omega_a(1-a)$ know as $\omega aCDM$ [5, 6].

In this paper, we investigate the suitability to describe the observed universe of three dark energy models: the standard ΛCDM, ωCDM and $\omega aCDM$. All models assume $\Omega_\kappa = 0$. We explore the cosmological parameters: H_0, Ω_m, Ω_Λ and q_0 these cosmological models given in [7] (WMAP9 + H_0). We use 580 SNIa data given in UNION 2.1 (2011) [8] and 19 observational Hubble function $H(z)$ data obtained from Simon et al. [9], Stern et al.(2010) [10] and Moresco et al. (2012) [11]. with redshifts ranging from $0.1 < z < 2.0$.

Our paper is organized as follows. In Sections 2 and 3 we present the basic equations of the three dark energy models studied. In section 4 is describes the data analyses with $H(z)$ and SNIa. In Section 5 we show the results and discussions. The conclusions are shown in Section 6.

2. Observational Constraints

2.1 Hubble Evoluction

The Hubble function is given

$$H(z) = H_0\sqrt{\Omega_\kappa(1+z)^2 + \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_\Lambda(1+z)^{3(1+\omega)}}, \tag{2.1}$$

where $\Omega_m + \Omega_\kappa + \Omega_\Lambda + \Omega_r = 1$. As $\Omega_r << \Omega_m$ today, thus the Ω_r term is usually omitted the interval we are interested. The ΛCDM model assumes $\omega = -1$. The free parameters in this model are: Ω_m and Ω_Λ. We can consider ω as free parameter in the ωCDM model.

There are many different parametrizations of the equation of the state parameter ω. Here we use the CPL parametrization ($\omega aCDM$ model). In this case, the equation of the state is given

$$\omega_z = \omega_0 + \omega_a\left(\frac{z}{1+z}\right), \tag{2.2}$$

where ω_0 and ω_a are free parameters to be fit with observational data.

The $H(z)$ determinations are based on the differential age method that relates the Hubble parameter directly to the measurable quantity dt/dz, by $H(z) = \dot{a}/a = -\dot{z}/(1+z)$.

2.2 Distance Modulus

SNIa data give measurements of the luminosity distance $d_l(z)$ through that of the distance modulus of each spernovae

$$\mu = 5\log\left[d_L(z)\right] + 25, \tag{2.3}$$

where $d_L = (1+z)\int_0^z \frac{dz'}{H(z')}$ (Mpc).

3. Cosmological Consequence

3.1 Deceleration Parameter

The deceleration parameter is a way of quantifying the rate at which the universe is expanding. In terms of the redshift it is given

$$q(z) = \frac{(1+z)}{H(z)}H'(z) - 1, \tag{3.1}$$

where $H'(z) = \frac{dH}{dz}$.

4. Data Analyses

We estimate the best-fit values for the cosmological parameters by minimizing a χ_H^2 function.

$$\chi^2_{H(z)} = \sum_{i=1}^{n} \frac{\left[H_t^i - H_o^i\right]^2}{\sigma_i^2}, \tag{4.1}$$

where the H_t^i is the predicted value of $H(z)$ in the cosmological models given in equation 2.1 and H_o^i is the observational value. The σ_i is the uncertainty in the individual data.

Similarly to the $H(z)$ data, we estimated the best-fit values with SNIa by using a χ^2 function, with

$$\chi^2_{SNIa} = \sum_{i=1}^{n} \frac{\left[\mu_t^i - \mu_o^i\right]^2}{\sigma_i^2}, \tag{4.2}$$

where the μ_t^i is the predicted value of distance modulus in the cosmological models given in equation 2.3 and μ_o^i is the observational value. The σ_i is the uncertainty in the individual data.

We show the 1σ and 2σ confidence intervals on two-dimensional parameter spaces.

5. Results and Discussions

The Tables 1 and 2 show our statistical results. We use two different observational data and our results are equivalent. It can be seen that the all models show the dark energy component dominant in the universe today with $\Omega_\Lambda \approx 0.70$ and $\Omega_m \approx 0.30$. The our results are consistent with other references, for example [12].

The Figures 1 shows the evolution of the Hubble parameter (Eq. 2.1) and the predicted distance modulus (Eq. 2.2) for the best-fit values for cosmological parameters given in Tables 1 and 2. The Figure 2 shows the 1σ and 2σ confidence levels for the cosmological parameters given in Tables 1 and 2 for the ΛCDM, ωCDM and $\omega a CDM$ models, respectiviely.

	ΛCDM	ωCDM	$\omega a CDM$
H_0	69.2 ± 1.4	70.1 ± 2.0	72.6 ± 2.5
ω_0	-1 (WMAP9)	-1.12 ± 0.10 (WMAP9)	-1.34 ± 0.18(WMAP9)
ω_a	0	0	0.85 ± 0.47 (WMAP9)
Ω_Λ	0.69 ± 0.04	0.68 ± 0.04	0.75 ± 0.05
Ω_m	0.31 ± 0.04	0.32 ± 0.04	0.25 ± 0.05
χ^2_ν	0.691	0.691	0.687

Table 1: Best-fit with $H(z)$ data

	ΛCDM	ωCDM	$\omega a CDM$
H_0	69.2 ± 1.4	70.2 ± 2.4	70.0 ± 2.5
ω_0	-1 (WMAP9)	-1.12 ± 0.10 (WMAP9)	-1.34 ± 0.18 (WMAP9)
ω_a	0	0	0.85 ± 0.47 (WMAP9)
Ω_Λ	0.69 ± 0.04	0.68 ± 0.05	0.67 ± 0.05
Ω_m	0.31 ± 0.04	0.32 ± 0.05	0.33 ± 0.04
χ^2_ν	0.980	0.998	0.994

Table 2: Best-fit with SNIa data

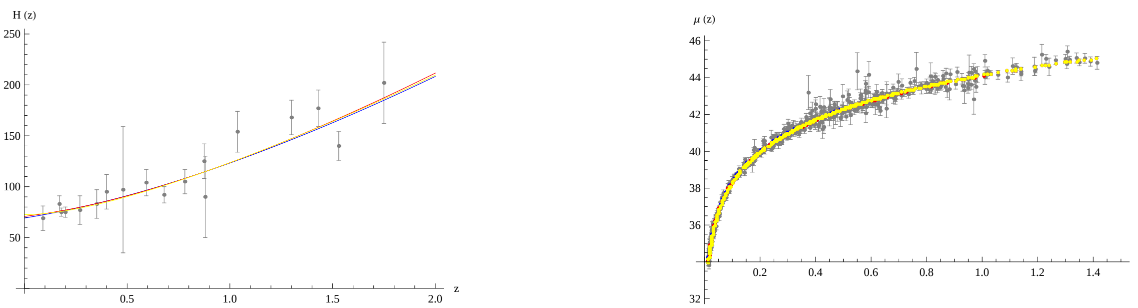
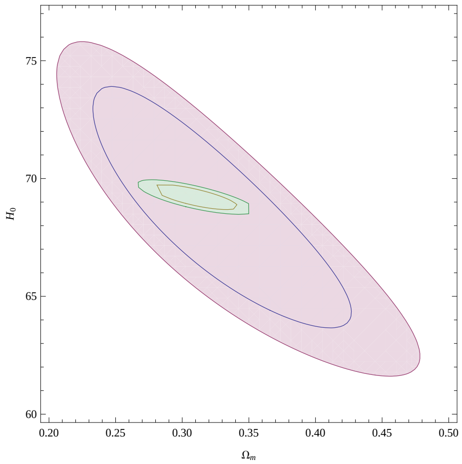
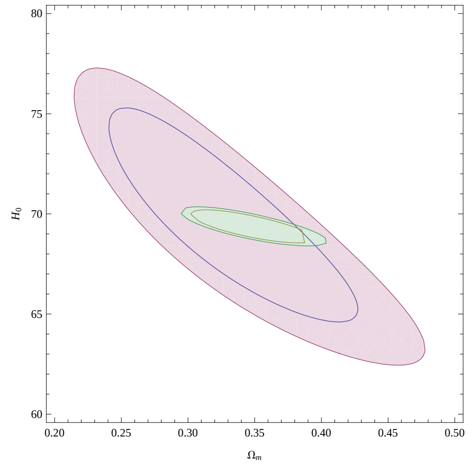


Figure 1: The evolution the Hubble (left panel) and distance modulus (right panel) as a function of the redshift. The curves correspond to the best-fit values for ΛCDM (blue), ωCDM (red), $\omega a CDM$ (yellow) models.

The Figure 3 shows $q(z)$ as function of the redshift (Eq. 3) for the best-fit values presented in Table 1. The values of the q_0 and z_t for each cosmological model are given in Table 3. As can be seen from this figure, the universe was decelerated in the past and today it is in accelerated expansion with transition redshift $z_t \approx 0.65$ and $q_0 < 0$.





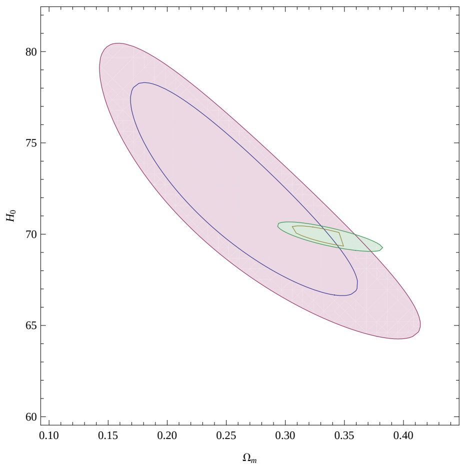


Figure 2: 1σ (inner contour) and 2σ (outer contour) confidence levels for the ΛCDM (left panel), ωCDM (right panel) and $\omega aCDM$ (bottom panel). The purple and green colors show the $H(z)$ and SNIa data, respectively.

	ΛCDM	ωCDM	$\omega aCDM$
q_0	-0.535 ± 0.010	-0.653 ± 0.015	-1.007 ± 0.020
z_t	0.645 ± 0.015	0.656 ± 0.010	0.587 ± 0.015

Table 3: Deceleration parameter and transition redshift

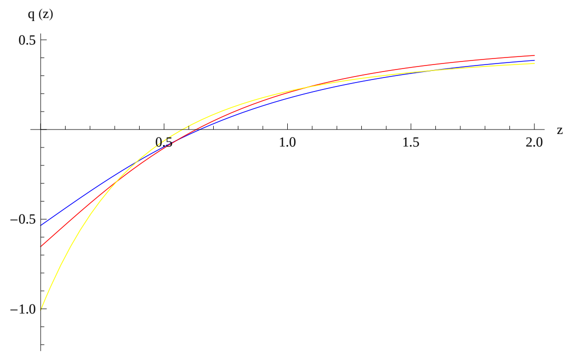


Figure 3: Deceleration parameter as a function of z. The curves correspond to the best-fit values for ΛCDM (blue), ωCDM (red) and $\omega aCDM$ (yellow) models.

6. Conclusions

Our main conclusions are:

- The Dark energy appears in all models as the dominant component of the density of the universe today;
- Our statistical results show that the ΛCDM model is still in good agreement with observational data; but a time evolving dark energy can not be exclused;
- All models fit very well the observational data: $H(z)$ and SNIa for $z < 1.5$ and they indicate the transition to cosmic acceleration with $q_0 < 0$ and $z_t \approx 0.65$.

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