Reconstructing the properties of dark energy from recent observations

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Abstract. We explore the properties of dark energy from recent observational data, including the Gold Sne Ia, the baryonic acoustic oscillation peak from SDSS, the CMB shift parameter from WMAP3, the x-ray gas mass fraction in clusters and the Hubble parameter versus redshift. The ΛCDM model with curvature and two parameterized dark energy models are studied. For the ΛCDM model, we find that the flat universe is consistent with observations at the 1σ confidence level and a closed universe is slightly favored by these data. For two parameterized dark energy models, with the prior given on the present matter density, $\Omega_{m0}$, with $\Omega_{m0} = 0.24$, $\Omega_{m0} = 0.28$ and $\Omega_{m0} = 0.32$, our result seems to suggest that the trend of $\Omega_{m0}$ dependence for an evolving dark energy from a combination of the observational datasets is model-dependent.

Keywords: dark energy theory, supernova type Ia

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1. Introduction

The present cosmic accelerating expansion has been confirmed by various observations, including the type Ia supernovae (Sne Ia) [1]–[6], CMB [7]–[11], large scale structure (LSS) [12,13], etc. In order to explain this observed phenomenon, it is usually assumed that there exists, in the universe, an exotic energy component with negative pressure, named dark energy (see [14]–[17] for recent reviews), which presumably began to dominate the evolution of the universe only recently. The simplest candidate of dark energy is the cosmological constant $\Lambda$ [18]–[21]. It fits the observational data very well, but at the same time, it also encounters two problems, i.e. the cosmological constant problem (why is the inferred value of the cosmological constant so tiny (120 orders of magnitude lower) compared to the typical vacuum energy values predicted by particle physics?) and the coincidence problem (why is its energy density comparable to the matter density right now?). Therefore, some dynamical scalar fields, such as quintessence [22]–[24], phantom [25], quintom [26], etc, are suggested as alternative candidates of dark energy. One of the features of these scalar field models is that their equations of state parameter, $w$, which embodies both gravitational and evolutionary properties of dark energy, is evolving with the cosmic expansion.

On the other hand, the growing number of dark energy models has prompted people to adopt a complementary approach, which assumes an arbitrary parameterization for the equation of state $w(z)$ in a model-independent way and aims to reconstruct the properties of dark energy directly from observations. Currently, there are many model-independent parameterizations (see, for example, [27]–[32]). In general, using these parameterizations and the observational data, one can determine the present value of $w$ and whether it evolves as the universe expands, in particular, whether the phantom dividing line (PDL) is crossed. In this regard, Nesseris and Perivolaropoulos [33] have used the Chevallier–Polarski–Linder parameterization $w(z) = w_0 + w_1 z / (1 + z)$ [28] to explore the properties.
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of dark energy with some observational data (including new Gold Sne Ia, SNLS Sne Ia, CMB, BAO, the cluster baryon gas mass fraction (CBF) and 2dF galaxy redshift survey (2dFGRS)) and found that the Gold dataset mildly favors dynamically evolving dark energy with the crossing of the PDL while the SNLS does not, and the combination of CMB + BAO + CBF + 2dFGRS mildly favors the crossing of PDL only for low values of $\Omega_{m0}$ ($\Omega_{m0} \leq 0.25$) prior considered and with a higher prior matter density the evolving features of dark energy becomes weaker and weaker. A similar trend of $\Omega_{m0}$ dependence was found using the model [34], $w(z) = \frac{(1 + z)}{3}(A_1 + 2A_2(1 + z))/\Omega_{DE} - 1$, with the CMB and BAO. However, constraints from a combination of the supernovae and other observational data have not been analyzed in [33], and although that of the Sne and CMB + BAO was examined in [34], the marginalization was considered only for $\Omega_{m0} = 0.28 \pm 0.03$ prior. Therefore, it remains interesting to see what happens to the conclusions reached in [33,34] when the combination of all observational data is analyzed for different $\Omega_{m0}$ prior considered. The present paper aims to fill the gap. We discuss the constraints from the combination of different observational datasets. Besides the datasets of Sne Ia, BAO and CMB, in our analysis we add the datasets of the x-ray gas mass fraction in clusters and the Hubble parameter versus redshift. Firstly the $\Lambda$CDM model with curvature is discussed. Then, two parameterized dark energy models, $w(z) = w_0 + w_1 z/(1 + z)$ and $w(z) = \frac{(1 + z)}{3}(A_1 + 2A_2(1 + z))/\Omega_{DE} - 1$, are studied to see if the properties of dark energy thus reconstructed are model-independent.

2. The observational data

2.1. The Gold Sne Ia data

The Sne Ia data considered in this paper is the 182 Gold set. This set was released by Riess et al [4] with a consistent and robust manner. It consists of 119 previously published data points [3], 16 points discovered recently by the Hubble Space Telescope (HST) and 47 points from the first year release of the SNLS dataset [5]. For these Sne Ia, the data is released in the form of distance modulus $\mu$, which is relative to the luminosity distance $d_L$ through

$$\mu(z, H_0, p_j) = 5 \log_{10}[d_L(z, p_j)] + M. \quad (1)$$

Here for a flat universe $d_L = (1 + z)\int_0^z dz'/E(z', p_j)$ with $E^2(z) = H^2(z)/H_0^2 = \Omega_{m0} + (1 - \Omega_{m0}) \exp[3 \int_0^z (dz'/(1 + z'))(1 + w(z'))], M = M - 5 \log_{10}(H_0), H_0 = 100h, M$ is the absolute magnitude of the object and $p_j$ denote the model parameters of dark energy. The constraints on the dark energy models from Sne Ia data can be obtained by the maximum likelihood method, so the best fit values for model parameters is determined by minimizing

$$\chi^2_{Sne}(H_0, p_j) = \sum_i \frac{[\mu(z_i, H_0, p_j) - \mu_{obs,i}]^2}{\sigma^2_{\mu_{obs,i}}} \quad (2)$$

2.2. The baryonic acoustic oscillation peak

From the large scale correlation function of luminous red galaxies in the Sloan Digital Sky Survey (SDSS), Eisenstein et al [13] found a baryonic acoustic oscillation peak, which
is consistent with the prediction from the acoustic oscillation in the primordial baryon–photon plasma at the recombination. Thus this peak remarkably confirms the Big Bang cosmology. Meanwhile it also provides a ruler to constrain the dark energy models, which can be used usually by a dimensionless parameter $A$:

$$A(p_j) = \frac{\sqrt{\Omega_m^0}}{E(z_1,p_j)^{1/3}} \left[ \frac{1}{z_1} \int_0^{z_1} \frac{dz}{E(z,p_j)} \right]^{2/3},$$

(3)

for a flat universe, where $z_1 = 0.35$ and $A$ is measured to be $A = 0.469 \pm 0.017$. The parameter $A$ is model-independent and clearly independent of the value of $h$ too. By minimizing

$$\chi^2_{\text{BAO}}(p_j) = \frac{[A(p_j) - 0.469]^2}{0.017^2}$$

(4)

we can obtain the constraints from BAO.

2.3. The CMB shift parameter

For the CMB data, we use the shift parameter $R$ to research the properties of dark energy, which can be expressed as [35]

$$R(p_j) = \frac{\sqrt{\Omega_m^0}}{E(z_1,p_j)^{1/3}} \int_0^{z_r} \frac{dz}{E(z,p_j)},$$

(5)

for a flat universe, where $z_r = 1048[1 + 0.00124(\Omega_b h^2)^{-0.738}[1 + g_1(\Omega_m h^2)^{0.678}], g_1 = 0.078(\Omega_b h^2)^{-0.238}[1 + 39.5(\Omega_b h^2)^{0.763}]^{-1}$ and $g_2 = 0.56[1 + 21.1(\Omega_b h^2)^{1.81}]^{-1}$ [36]. To calculate $z_r$, we let $\Omega_b h^2 = 0.024$. The results of three-year WMAP data [11] give $R = 1.70 \pm 0.03$ [37]. Let us note that the quantity $R$ from CMB measurement is dependent on the value of $\Omega_m h^2$. Thus when using this parameter it is required to marginalize over $\Omega_m h^2$ or assign some specific value to $h$. In our discussion we give a prior value $h = 0.72$. We then place constraints on cosmological models using this shift parameter by minimizing

$$\chi^2_{\text{CMB}}(p_j) = \frac{[R(p_j) - 1.70]^2}{0.03^2}.$$  

(6)

2.4. The baryon gas mass fraction of galaxy cluster

Under the basic assumption that the baryon gas mass fraction in a cluster is constant, a comparison of the gas mass fraction of galaxy clusters, $f_{\text{gas}} = M_{\text{gas}}/M_{\text{tot}}$, can be used to constrain the cosmological models. Following Allen et al [38,39] we fit the $f_{\text{gas}}$ data to a model described by

$$f_{\text{gas}}^{\text{mod}}(z,p_j) = \frac{b\Omega_b(2h)^{3/2}}{(1 + 0.19h^{1/2})\Omega_m^0} \left[ \frac{d_A^{\text{SCDM}}(z,p_j)}{d_A^{\text{mod}}(z,p_j)} \right]^{3/2},$$

(7)

where $b$ is a parameter motivated by gas dynamical simulations, $d_A = d^*/(1 + z)^2$ is the angular diameter distance and $d_A^{\text{SCDM}}$ is the angular diameter distance corresponding to the standard cold dark matter (SCDM) universe ($\Omega_m^0 = 1$ for a flat universe). Following Nesseris and Perivolaropoulos [33], we define $\lambda = b\Omega_b(2h)^{3/2}/(1 + 0.19h^{1/2})\Omega_m^0$ and treat
it as a nuisance parameter. Using the theoretical method given in [33] to marginalize over λ, we can obtain the constraints by minimizing

\[ \chi^2_{gas}(p_j) = C - \frac{B^2}{A}, \]  

(8)

where \( A = \sum_i \left( \frac{\tilde{f}_{\text{gas}}}{\sigma_{\tilde{f}_{\text{gas},i}}} \right)^2 \), \( B = \sum_i \frac{f_{\text{obs}}}{\sigma_{\tilde{f}_{\text{gas},i}}} \), \( C = \sum_i \left( \frac{f_{\text{obs}}}{\sigma_{\tilde{f}_{\text{gas},i}}} \right)^2 \), and \( \tilde{f}_{\text{gas}} = \left[ \frac{\sigma_{A}}{A} \right]^{3/2} \). Here, 26 cluster data points given in [39] are used.

### 2.5. The Hubble parameter data

Based on differential ages of passively evolving galaxies determined from the Gemini Deep Deep Survey [40] and archival data [41] at redshift 0 \( \lesssim z \lesssim 1.8 \), Simon et al [42] obtained 9 data points of \( H(z) \) at redshift \( z_i \), which can be used to test the cosmological models by minimizing

\[ \chi^2_H(H_0, p_j) = \sum_i \frac{[H_{\text{obs}}(z_i) - H_{\text{th}}(z_i, H_0, p_j)]^2}{\sigma_{H_i}^2}. \]  

(9)

Recently these 9 Hubble parameter data points have been studied extensively by many authors [42, 43]: however, it does not provide a tight constraint on dark energy models.

Thus the constraints on cosmological models from a combination of the above discussed observational datasets can be obtained by minimizing

\[ \chi^2(H_0, p_j) = \chi^2_{\text{sne}}(H_0, p_j) + \chi^2_{\text{BAO}}(p_j) + \chi^2_{\text{CMB}}(p_j) + \chi^2_{\text{gas}}(p_j) + \chi^2_H(H_0, p_j). \]  

(10)

Since we are interested in the model parameters, \( H_0 \) becomes a nuisance parameter and is marginalized by a theoretical method given in [44] in calculating \( \chi^2_{\text{sne}} \) and \( \chi^2_H \).

### 3. Results

The ΛCDM model with curvature is firstly discussed with the observational data. The results are shown in figure 1 for a combination of the above discussed observational datasets. At a 95.4% confidence level we obtain \( \Omega_{m0} = 0.29^{+0.04}_{-0.04} \) and \( \Omega_{k0} = -0.016^{+0.030}_{-0.029} \) with \( \chi^2 = 196.8 \). It is easy to see that a spatially flat universe is consistent with the observations at a 68% confidence level and a closed universe is somewhat favored by these datasets.

Then we study, in the spatially flat case, the observational constraints on the following two-parameter models considered in [33] and [34] respectively:

\begin{align*}
\text{Mod1:} & \quad w(z) = w_0 + w_1 \frac{z}{1+z}, \\
\text{Mod2:} & \quad w(z) = \frac{1 + z}{3} \frac{A_1 + 2A_2(1+z)}{\Omega_{DE}} - 1,
\end{align*}

(11)\hspace{1cm}(12)

where \( \Omega_{DE} = A_1(1+z) + A_2(1+z)^2 + 1 - \Omega_{m0} - A_1 - A_2 \) [34]. In order to find out whether the constraints from the observations are dependent on the choice of the value of \( \Omega_{m0} \), we give three prior values of \( \Omega_{m0} \) with \( \Omega_{m0} = 0.24 \), \( \Omega_{m0} = 0.28 \) and \( \Omega_{m0} = 0.32 \). Tables 1 and 2 display constraints on model parameters with 95% confidence.
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Figure 1. The 1σ, 2σ and 3σ confidence contours for a ΛCDM universe with curvature from the combination of Sne Ia, BAO, CMB, the x-ray gas mass fraction in clusters and Hubble parameter data.

level. From the best fit values given in the tables one can see that the BAO + CMB alone indicates that the evolving features of dark energy become weaker and weaker with a higher prior matter density, which is the same as obtained in [33, 34]. However, the trend is reversed for the Gold + CMB, Gold + CMB + BAO, Gold + CMB + BAO + f_{\text{gas}} and Gold + CMB + BAO + f_{\text{gas}} + H(z). Meanwhile we find the effects of adding the f_{\text{gas}} and Hubble parameter datasets are not very significant, suggesting that the model parameters are strongly constrained by CMB + BAO + Gold. In figure 2 we show the constraints on model parameters from all the datasets. The upper and lower panels show the constraints on Mod1 and Mod2, respectively. In figure 2 the red dot denotes the flat ΛCDM model. This figure clearly shows that the ΛCDM model is consistent with the observations at the 95% confidence level. In addition one can find that the best fit of model parameters is closest to the ΛCDM when Ω_{m0} = 0.24, which can also be seen from the tables.

In figure 3 we plot the evolutionary curves of w(z) for these dark energy models with different prior values over Ω_{m0}. The upper and lower panels show the results of Mod1 and Mod2, respectively. In figure 3 the solid lines show the evolution of w(z) with the best fit values for the model parameters, and the dotted lines are for 1σ and 2σ error bars. For Mod1 the best fit curves show that the combination of the datasets considered in this paper favors an evolving dark energy and a crossing of the phantom dividing line in the near past, and suggests that the present value of w is very likely less than −1. Remarkably, these conclusions are almost insensitive to the chosen value of matter density, in a clear contrast to those obtained in [33] where it was found that, when the Sne data are
Table 1. The best-fit data of Mod1 with prior value $\Omega_{m0}$. In the table G + C + B, G + C + B + $f$ and G + C + B + $f$ + $H$ represent the Gold + BAO + CMB, Gold + BAO + CMB + $f_{\text{gas}}$ and Gold + BAO + CMB + $f_{\text{gas}}$ + $H(z)$, respectively.

|       | $\Omega_{m0} = 0.24$ |       | $\Omega_{m0} = 0.28$ |       | $\Omega_{m0} = 0.32$ |
|-------|----------------------|-------|----------------------|-------|----------------------|
|       | $w_0$ | $w_1$ | $\chi^2_{\text{Min}}$ | $w_0$ | $w_1$ | $\chi^2_{\text{Min}}$ | $w_0$ | $w_1$ | $\chi^2_{\text{Min}}$ |
| Gold  | -1.28$^{+0.59}_{-0.63}$ | 2.64$^{+3.08}_{-3.14}$ | 156.5 | -1.38$^{+0.67}_{-0.72}$ | 2.75$^{+3.52}_{-3.75}$ | 156.5 | -1.49$^{+0.79}_{-0.85}$ | 2.81$^{+4.13}_{-4.62}$ | 156.6 |
| Gold + BAO | -1.45$^{+0.52}_{-0.55}$ | 3.32$^{+2.79}_{-2.63}$ | 158.1 | -1.30$^{+0.53}_{-0.59}$ | 2.43$^{+3.07}_{-3.40}$ | 156.8 | -1.11$^{+0.65}_{-0.64}$ | 1.29$^{+3.50}_{-4.28}$ | 160.7 |
| CMB + BAO | -1.47$^{+0.85}_{-0.69}$ | 1.48$^{+1.51}_{-5.18}$ | 0.001 | -1.01$^{+0.94}_{-0.71}$ | 0.61$^{+1.40}_{-6.05}$ | 0.001 | -0.60$^{+1.05}_{-0.71}$ | -0.37$^{+1.82}_{-6.75}$ | 0.001 |
| Gold + CMB | -0.90$^{+0.42}_{-0.37}$ | 0.27$^{+1.00}_{-1.38}$ | 161.8 | -1.05$^{+0.44}_{-0.40}$ | 0.81$^{+0.81}_{-2.08}$ | 158.6 | -1.22$^{+0.43}_{-0.56}$ | 1.28$^{+0.73}_{-1.78}$ | 157.4 |
| G + C + B | -1.04$^{+0.35}_{-0.31}$ | 0.63$^{+0.79}_{-1.62}$ | 165.1 | -1.05$^{+0.39}_{-0.34}$ | 0.79$^{+0.74}_{-1.91}$ | 158.6 | -1.06$^{+0.44}_{-0.36}$ | 0.96$^{+0.68}_{-2.24}$ | 160.8 |
| G + C + B + $f$ | -1.07$^{+0.35}_{-0.30}$ | 0.68$^{+0.76}_{-1.71}$ | 191.1 | -1.10$^{+0.40}_{-0.32}$ | 0.88$^{+0.71}_{-2.08}$ | 185.9 | -1.13$^{+0.47}_{-0.35}$ | 1.16$^{+0.62}_{-2.54}$ | 189.6 |
| G + C + B + $f$ + $H$ | -1.07$^{+0.30}_{-0.30}$ | 0.71$^{+0.73}_{-1.42}$ | 200.2 | -1.09$^{+0.36}_{-0.32}$ | 0.85$^{+0.70}_{-1.84}$ | 194.9 | -1.12$^{+0.47}_{-0.35}$ | 1.06$^{+0.65}_{-2.54}$ | 199.1 |
In the table $G + C + B$, $G + C + B + f$ and $G + C + B + f + H$ represent the Gold + BAO + CMB, Gold + BAO + CMB + $f_{\text{gas}}$ and Gold + BAO + CMB + $f_{\text{gas}} + H(z)$, respectively.

| Parameter | $\Omega_{m0} = 0.24$ | | $\Omega_{m0} = 0.28$ | | $\Omega_{m0} = 0.32$ | |
|-----------|-------------------|---|-------------------|---|-------------------|---|
|           | $A_1$ | $A_2$ | $\chi^2_{\text{Min}}$ | $A_1$ | $A_2$ | $\chi^2_{\text{Min}}$ | $A_1$ | $A_2$ | $\chi^2_{\text{Min}}$ |
| Gold      | $-3.61^{+4.96}_{-5.52}$ | $1.60^{+2.25}_{-1.95}$ | 156.5 | $-3.39^{+4.97}_{-5.53}$ | $1.44^{+2.25}_{-1.96}$ | 156.5 | $-3.17^{+4.98}_{-5.54}$ | $1.27^{+2.26}_{-1.96}$ | 156.5 |
| Gold + BAO| $-4.69^{+4.55}_{-5.17}$ | $2.00^{+2.14}_{-1.83}$ | 158.3 | $-3.01^{+4.48}_{-5.09}$ | $1.30^{+1.24}_{-1.13}$ | 156.7 | $-1.36^{+4.40}_{-5.02}$ | $0.62^{+2.07}_{-1.75}$ | 160.6 |
| CMB + BAO | $-1.49^{+2.52}_{-2.25}$ | $0.41^{+0.72}_{-0.71}$ | 0.001 | $-0.21^{+2.90}_{-2.58}$ | $0.14^{+0.81}_{-0.79}$ | 0.001 | $1.08^{+3.29}_{-2.91}$ | $-0.12^{+0.89}_{-0.88}$ | 0.001 |
| Gold + CMB| $0.67^{+1.60}_{-1.70}$ | $-0.11^{+0.57}_{-0.50}$ | 161.6 | $-0.33^{+1.82}_{-1.96}$ | $0.20^{+0.68}_{-0.61}$ | 159.1 | $-1.38^{+2.02}_{-2.19}$ | $0.55^{+0.78}_{-0.69}$ | 157.4 |
| G + C + B | $0.11^{+1.49}_{-1.60}$ | $0.04^{+0.56}_{-0.48}$ | 166.1 | $-0.35^{+1.65}_{-1.77}$ | $0.21^{+0.63}_{-0.55}$ | 159.2 | $-0.70^{+1.79}_{-1.93}$ | $0.35^{+0.71}_{-0.62}$ | 160.7 |
| G + C + B + f | $-0.05^{+1.42}_{-1.52}$ | $0.07^{+0.54}_{-0.46}$ | 192.1 | $-0.53^{+1.58}_{-1.69}$ | $0.25^{+0.61}_{-0.54}$ | 186.3 | $-0.91^{+1.71}_{-1.85}$ | $0.40^{+0.68}_{-0.60}$ | 189.2 |
| G + C + B + f + H | $-0.16^{+1.44}_{-1.42}$ | $0.10^{+0.52}_{-0.45}$ | 201.5 | $-0.47^{+1.54}_{-1.60}$ | $0.23^{+0.57}_{-0.51}$ | 195.3 | $-0.73^{+1.62}_{-1.71}$ | $0.33^{+0.63}_{-0.56}$ | 198.8 |
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Figure 2. The constraints on two parameterized dark energy models from the combination of the Gold SNe Ia, BAO, CMB, the x-ray gas mass fraction in clusters and the Hubble parameter data. The upper and lower panels, respectively, show the results of $w(z) = w_0 + w_1 z/(1 + z)$ (Mod1) and $w(z) = ((1 + z)/3)(A_1 + 2A_2(1 + z))/\Omega_{DE} - 1$ (Mod2) with three different priors over $\Omega_m$: $\Omega_m = 0.24$, $\Omega_m = 0.28$ and $\Omega_m = 0.32$. The red dot represents the $\Lambda$CDM model.

not combined with other observational ones, the evolving property becomes weaker and weaker with higher matter density and the phantom divide may not be crossed with the increasing of matter density. With this being said, it should be pointed out, however, that higher values of $\Omega_m$ lead to larger errors, especially at the $2\sigma$ level, as can be seen from the tables. The results for Mod2 are shown in the lower panels of figure 3. Unlike Mod1, the best fit curves show that the properties reconstructed depend on the chosen value of matter density. For $\Omega_m = 0.24$, a very mildly evolving dark energy is obtained, but with the increase of $\Omega_m$ prior considered, the evolving feature of dark energy becomes more evident. This trend is just the opposite to that found in [34] for just BAO + CMB data. These discrepancies can also be found in tables 1 and 2. However, at the $2\sigma$ confidence level for Mod1 and Mod2 the cosmological constant cannot be ruled out. In addition, we also find that the stringent constraint on $w(z)$ happens around a redshift $z \sim 0.5$, which is consistent with that obtained in [31, 45].

Finally, the evolution of the decelerating parameter $q$ with the redshift is studied for these two parameterized dark energy models with $\Omega_m = 0.28$. The results are shown in figure 4 with the left and right panel corresponding to the results of Mod1.
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Figure 3. The evolution of $w(z)$. The upper and lower panels, respectively, show the results of Mod1 and Mod2 with $\Omega_m = 0.24$, $\Omega_m = 0.28$ and $\Omega_m = 0.32$. The solid line shows the evolution of $w(z)$ with the model parameters at the best fit values, and the dotted lines are for the 1$\sigma$ and 2$\sigma$ errors.

and Mod2, respectively. In this figure the dashed lines are the results of $\Lambda$CDM model with $\Omega_m = 0.28$, the solid lines show the evolution of $q(z)$ when $\Omega_m = 0.28$, the model parameters are the best fit values and the dotted lines are for 1$\sigma$ errors. The figure shows that the present value of the deceleration parameter $q_0$ is less than zero, indicating that the cosmos is undergoing an accelerating expansion, but for different models the value of $q_0$ is different.

4. Conclusion

In this paper, we have reconstructed the properties of dark energy from recent observational data, including the Gold Sne Ia, the baryonic acoustic oscillation peak from SDSS, the CMB shift parameter, the x-ray gas mass fraction in clusters and the Hubble parameter data. The $\Lambda$CDM model with curvature and two parameterized dark energy models are discussed. We find that a spatially flat universe is allowed by these datasets at the 68% confidence level, and a closed universe is slightly favored by the observations. For two parameterized dark energy models, we give the priors on $\Omega_m$ with $\Omega_m = 0.24$, $\Omega_m = 0.28$ and $\Omega_m = 0.32$. For the spatially flat case, the constraints on model parameters and the evolutions of $w(z)$ and $q(z)$ are studied. The Gold + CMB + BAO give the strong constraints on model parameters. If Mod1 parameterization is used, the
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**Figure 4.** The behavior of $q(z)$. The left and right panel, respectively, shows the results of Mod1 and Mod2 with $\Omega_{m0} = 0.28$. The dashed line represents the $\Lambda$CDM with $\Omega_{m0} = 0.28$, the solid line shows the evolution of $q(z)$ with $\Omega_{m0} = 0.28$ and the model parameters at the best fit values and the dotted lines are for the $1\sigma$ error.

best fit curves in figure 3 show that the combination of the datasets considered in this paper favors an evolving dark energy, a crossing of the phantom dividing line in the near past, and the present value of $w$ being very likely less than $-1$. Remarkably, these conclusions are almost insensitive to the chosen value of matter density, in sharp contrast to those obtained in [33] where the SNe data are not combined with other observational ones. However, the best fit curves in figure 3 indicate that the properties of dark energy reconstructed using Mod2 parameterization depend on the chosen value of matter density. For $\Omega_{m0} = 0.24$, a very mildly evolving dark energy is obtained, but with the increase of $\Omega_{m0}$ prior considered, the evolving feature of dark energy becomes more evident. This trend is just the opposite to that found in [34] for just BAO + CMB data. Therefore, our result seems to suggest that the trend of $\Omega_{m0}$ dependence for an evolving dark energy is model-dependent. It should be noted, however, that at the $2\sigma$ confidence level, the cosmological constant are allowed for both Mod1 and Mod2.

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