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Observational constraints on the accelerating universe in the framework of a 5D bounce cosmological model*

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In the framework of a five-dimensional (5D) bounce cosmological model, a useful function $f(z)$ is obtained by giving a concrete expression of deceleration parameter $q(z) = q_1 + \frac{q_2}{1+\ln(1+z)}$. Then using the obtained Hubble parameter $H(z)$ according to the function $f(z)$, we constrain the accelerating universe from recent cosmic observations: the 192 ESSENCE SNe Ia and the 9 observational $H(z)$ data. The best fitting values of transition redshift z_T and current deceleration parameter q_0 are given as $z_T = 0.65^{+0.25}_{-0.12}$ and $q_0 = -0.76^{+0.15}_{-0.15}(1\sigma)$. Furthermore, in the 5D bounce model it can be seen that the evolution of equation of state (EOS) for dark energy $w_{\rm de}$ can cross over -1 at about $z = 0.23$ and the current value $w_{0\rm de} = -1.15 < -1$. On the other hand, by giving a concrete expression of model-independent EOS of dark energy $w_{\rm de}$, in the 5D bounce model we obtain the best fitting values $z_T = 0.66^{+0.11}_{-0.08}$ and $q_0 = -0.69^{+0.10}_{-0.10}(1\sigma)$ from the recently observed data: the 192 ESSENCE SNe Ia, the observational $H(z)$ data, the 3-year Wilkinson Microwave Anisotropy Probe (WMAP), the Sloan Digital Sky Survey (SDSS) baryon acoustic peak and the x-ray gas mass fraction in clusters.

Keywords: bounce cosmology, deceleration parameter, equation of state (EOS), dark energy (DE)
PACC: 9880

1. Introduction

The type Ia supernovae (SNe Ia) investigations,[1] the results of cosmic microwave background (CMB) obtained from the Wilkinson Microwave Anisotropy Probe (WMAP)[2] observations, and the surveys of galaxies[3] all suggest that the expansion of present universe is speeding up rather than slowing down. If the evolution of universe is believed to follow the standard cosmology (i.e. the hot big bang model), the accelerated expansion of the present universe is usually attributed to the fact that dark energy (DE) is an exotic component with negative pressure. Though DE has not been found yet, many kinds of DE models have already been constructed such as ΛCDM,[4] quintessence,[5] phantom,[6] generalized Chaplygin gas (GCG),[7] modified Chaplygin gas,[8] quintom,[9] hessence,[10] holographic dark energy,[11] and so forth. Furthermore, to remove the dependence of special properties of extra energy components, a parametrized equation of state (EOS) is assumed for DE. This is also commonly called the model-independent method, and it describes the possible evolution of DE. For example, $w(z) = w_0 + w_1 z$,[12] $w(z) = w_0 + \frac{w_1 z}{1+z}$,[13] $w(z) = w_0 + \frac{w_1 z}{1+z^2}$,[14] $w(z) = w_0 + w_1 z \ln(1+z)$,[15] $w(z) = \frac{w_0}{1+w_1\ln(1+z)}$,[16] and

$$w_{\rm de} = \frac{1+z}{3}\frac{A_1 + 2A_2(1+z)}{A_1(1+z) + A_2(1+z)^2 + (1-\Omega_{0m}-A_1-A_2)} - 1.$$[17]

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The parameters w_0 and w_1, or, A_1 and A_2 are obtained by the best fitting estimations from cosmic observational datasets.

Beside the method of introducing a new special matter component DE to explain the accelerating universe, on the other hand, spacetime geometric approaches to explaining cosmological acceleration have also been considered, such as Randall–Sundrum (RS),[18] the Dvali–Gabadadze–Porrati (DGP) braneworld model[19] cosmology in which our three-dimensional universe is believed to be a lower-dimensional 'brane' embedded in a higher-dimensional 'bulk' spacetime. Space–Time–Matter (STM) theory, as a kind of extra dimensional theory, has also been applied to studying the cosmology and explaining the accelerating universe.[20] In the present paper, we consider a five-dimensional (5D) bounce cosmological model with the STM theory.

Our world may have more than four dimensions, which originates from the Kaluza–Klein idea,[21] and this idea has already been studied extensively from different viewpoints.[18,19,22,23] Among them, a kind of theory named STM theory was developed by combining the geometry and the matter.[24] According to the STM theory, 4D Einstein equations with matter could be recovered from 5D equations in apparent vacuum, and all the matter in our world is induced from the higher dimension, and so it is called induced matter. That is to say, in the STM theory, the 5D manifold is Ricci-flat ($R_{\rm AB} = 0$), while the 4D hypersurface is curved by the 4D induced matter. Mathematically, this approach is supported by Campbell's theorem that any analytical solution of the N-dimensional Einstein equations with a source can be locally embedded in an (N + 1)-dimensional Ricci-flat manifold.[25]

Within the framework of STM theory, a 5D cosmological solution was presented in Ref.[23], in which it was shown that the universe was characterized by having a 'Big Bounce' instead of a Big Bang singularity in the standard universe,[26] thereby it is called the 5D big bounce cosmological model. At the time of a 'bounce' of the universe, it corresponds to a nonzero minimal size of the universe. The 5D bounce cosmological model has already been studied in Ref.[27]. Furthermore, studies of this solution have also been applied to many other physical fields, including the embedded brane models,[28] the isometry with 5D black holes,[29] the cosmological evolution in the early universe,[30] the dark energy models,[31] and so on.

We know that this 5D cosmological solution contains two arbitrary functions $\eta(t)$ and $\nu(t)$.[23] From Ref.[32], it is easy to see that one of these two arbitrary functions, $\eta(t)$, has played an important role in the evolution of the universe. Rewriting $\eta(t)$ into a new function $f(z)$, the evolutions of cosmological quantities in the 5D bounce model have been given with respect to redshift z in Refs.[20, 33]. In the present paper, within the framework of the 5D bounce cosmological model, a useful function $f(z)$ is obtained by giving a concrete expression of deceleration parameter q or equation of state (EOS) of dark energy $w_{\rm de}$. Then using the obtained Hubble parameter $H(z)$ according to the function $f(z)$, we constrain the transition redshift z_T and the current deceleration parameter q_0 from the recently observed data: the 192 ESSENCE SNe Ia[34] (or the 182 Gold SNe Ia[35]), the observational $H(z)$ data[36] from the Gemini Deep Deep Survey (GDDS)[37] and archival data,[38] the 3-year WMAP,[39] the baryon acoustic oscillation (BAO) peak from the SDSS[40] and the x-ray gas mass fraction in clusters.[41]

The rest of this paper is organized as follows. In the next section, a 5D bounce cosmological model is introduced briefly. In Section 3, we apply recent cosmic observations to constraining the accelerating universe in the framework of the 5D bounce model. Given in Section 4 are the conclusions drawn from the present study.

2. Dark energy in a 5D bounce cosmological model

We consider a 5D bounce cosmological model as an alternative candidate to the standard 4D Friedmann–Robertson–Walker (FRW) model. Within the framework of STM theory, a 5D cosmological solution was originally given by Liu and Mashhoon in 1995.[23] Then, in 2001, Liu and Wesson restudied the solution and showed that it described a cosmological model with a big bounce as opposed to a big bang.[26] The 5D cosmological solution with a big bounce reads

$$\mathrm{d}S^2 = B^2\mathrm{d}t^2 - A^2\left(\frac{\mathrm{d}r^2}{1-kr^2} + r^2\mathrm{d}\Omega^2\right) - \mathrm{d}y^2, \quad (1)$$

where $\mathrm{d}\Omega^2 \equiv (\mathrm{d}\theta^2 + \sin^2\theta\mathrm{d}\phi^2)$,

$$A^2 = (\eta^2 + k)y^2 + 2\nu y + \frac{\nu^2 + K}{\eta^2 + k}, \quad (2)$$

and

$$B = \frac{1}{\eta}\frac{\partial A}{\partial t} \equiv \frac{\dot{A}}{\eta}. \tag{3}$$

Here $\eta = \eta(t)$ and $\nu = \nu(t)$ are two arbitrary functions of t, k is the 3D curvature index ($k = \pm 1, 0$), and K is a constant. From expression (2), it can be seen that A is a function of t and y. However, on a given $y =$ constant hypersurface, A becomes $A = A(t)$, which means that we consider a 4D supersurface embedded in a flat 5D spacetime. Note that in the 5D bounce model the scale factor A reaches a nonzero minimum at $t = t_b$, where t_b is the bouncing time. Therefore, the big bang singularity of the 4D standard cosmology is replaced by a big bounce.[26] Before the bounce, the universe contracts; after the bounce, it expands.

Furthermore, this solution satisfies the 5D vacuum equation $R_{AB} = 0$, so the three invariants are

$$I_1 \equiv R = 0, \quad I_2 \equiv R^{AB}R_{AB} = 0, \quad \text{and}$$
$$I_3 = R^{ABCD}R_{ABCD} = \frac{72K^2}{A^8}. \tag{4}$$

The invariant I_3 in expression (4) shows that K determines the curvature of the 5D manifold.

On a given $y =$ constant 4D hypersurface, the proper time can be defined as $\mathrm{d}\tau = B(t, y)\mathrm{d}t$ according to the 5D metric (1).[42] So the deceleration parameter q and Hubble parameter H in the 5D bounce cosmology are given as[42]

$$q(t, y) \equiv A\frac{\mathrm{d}^2A}{\mathrm{d}\tau^2}\Big/\left(\frac{\mathrm{d}A}{\mathrm{d}\tau}\right)^2 = -\frac{A\dot{\eta}}{\eta\dot{A}}, \tag{5}$$

$$H \equiv \frac{\dot{A}}{AB} = \frac{\eta}{A}, \tag{6}$$

from which we see that $\dfrac{\dot{\eta}}{\eta} > 0$ represents an accelerating universe, while $\dfrac{\dot{\eta}}{\eta} < 0$ represents a decelerating universe. So function $\eta(t)$ plays a crucial role in determining the properties of the universe at late time.

In the present paper, we assume that the induced matter contains two kinds of energy densities, i.e. ρ_m and ρ_{de}, where ρ_m contains baryon and dark matter (DM), while ρ_{de} involves dark energy component. Using the 4D part of the 5D metric (1) to calculate the 4D Einstein tensor yields

$${}^{(4)}G_0^0 = \frac{3(\eta^2 + k)}{A^2} = \rho_m + \rho_{\mathrm{de}}, \tag{7}$$

$${}^{(4)}G_1^1 = {}^{(4)}G_2^2 = {}^{(4)}G_3^3 = \frac{2\eta\dot{\eta}}{A\dot{A}} + \frac{\eta^2 + k}{A^2} = -(p_m + p_{\mathrm{de}}), \tag{8}$$

with

$$\rho_m = \rho_{0m}A_0^3A^{-3}, \quad p_m = 0, \tag{9}$$

$$p_{\mathrm{de}} = w_{\mathrm{de}}\rho_{\mathrm{de}}. \tag{10}$$

From expressions (7)–(10), we obtain the EOS of DE

$$w_{\mathrm{de}} = \frac{p_{\mathrm{de}}}{\rho_{\mathrm{de}}} = -\frac{2\eta\dot{\eta}/A\dot{A} + (\eta^2 + k)/A^2}{3(\eta^2 + k)/A^2 - \rho_{0m}A^{-3}}, \tag{11}$$

and the dimensionless density parameters of matter and dark energy

$$\Omega_m = \frac{\rho_m}{\rho_m + \rho_{\mathrm{de}}} = \frac{\rho_{0m}}{3(\eta^2 + k)A}, \tag{12}$$
$$\Omega_{\mathrm{de}} = 1 - \Omega_m, \tag{13}$$

where ρ_{0m} is the current value of matter density.

In the present paper, we consider the spatially flat ($k = 0$) cosmological model which is consistent with the recent cosmic observation for CMB from WMAP.[43] From expressions (5), (6) and (11)–(13), it is easy to see that these equations do not contain the second arbitrary function $\nu(t)$ explicitly. We define $\dfrac{\eta_0^2}{\eta^2(z)} = f(z)$, where $\eta_0 \equiv \eta(z = 0)$, and it can be seen that $f(0) = 1$ when $z = 0$. So, by using the relation $A_0/A = 1 + z$,[20] the deceleration parameter q and Hubble parameter H can be expressed in terms of redshift z, respectively, as[20]

$$q = \frac{1 + 3\Omega_{\mathrm{de}}w_{\mathrm{de}}}{2} = -\frac{(1 + z)}{2}\frac{\mathrm{d}\ln f(z)}{\mathrm{d}z}, \tag{14}$$

and

$$H^2 = H_0^2(1 + z)^2f(z)^{-1} \equiv H_0^2E^2(z), \tag{15}$$

where "0" denotes the current value of the variable, $E^2(z) = (1 + z)^2f(z)^{-1}$. From expression (15), it can be seen that the Hubble parameter H is determined by a function $f(z)$. The expressions (11)–(13) can be written as[20]

$$w_{\mathrm{de}} = -\frac{1 + (1 + z)\mathrm{d}\ln f(z)/\mathrm{d}z}{3 - 3\Omega_m}, \tag{16}$$
$$\Omega_m = \Omega_{0m}(1 + z)f(z), \tag{17}$$
$$\Omega_{\mathrm{de}} = 1 - \Omega_m. \tag{18}$$

Then according to expressions (14)–(18), we can describe the evolution of universe in the framework of a 5D bounce cosmological model if an expression of the function $f(z)$ is given. Next, we use the recent cosmic observations to constrain the accelerating universe with the 5D bounce model.

3. Constraints on the accelerating universe in a 5D bounce cosmological model

3.1. Constraints on the accelerating universe by parametrizing a deceleration parameter

Since type Ia supernovae behave as excellent standard candles, they can be used to directly measure the expansion rate of the universe up to high redshift for comparison with the present rate. Therefore, they provide direct information on the universe's acceleration and constrain the DE model. Theoretical DE model parameters are determined by minimizing the quantity

$$\chi^2_{\rm SNe}(H_0,\theta)=\sum_{i=1}^{N}\frac{(\mu_{\rm obs}(z_i)-\mu_{\rm th}(\theta,z_i))^2}{\sigma^2_{{\rm obs};i}}, \quad (19)$$

where $N=192$ for the SNe Ia data[34] compiled from 60 ESSENCE SNe,[44] 57 Supernova Legacy Survey (SNLS) SNe,[45] 45 nearby SNe,[1,46] and 30 new SNe at high redshift ($0.216\leq z\leq 1.755$) recently discovered by the Hubble Space Telescope (HST) and classed with 'Gold' SNe in Ref.[35]. The SNLS and the nearby SNe data have been refitted in Ref.[44] with the same lightcurve fitter used for the ESSENCE data. As regards the 30 HST SNe, it is necessary to perform a normalization.[47] Adopted in Ref.[34] was the low redshift SNe that these samples had in common in order to normalize the luminosity distances of the samples, and the error in the normalization was included in the distance errors for the HST SNe.[34,47] In summary, the 192 data points are from the ESSENCE project, or from other surveys with refitting or normalizing SNe according to the same lightcurve fitter used for the ESSENCE data. For simplicity, then we refer to these data as 192 ESSENCE SNe Ia data in the present paper. $\sigma^2_{{\rm obs};i}$ is the error due to flux uncertainty, intrinsic dispersion of SNe Ia absolute magnitude and peculiar velocity dispersion separately. θ denotes the model parameter. The theoretical distance modulus $\mu_{\rm th}$ is defined as

$$\begin{aligned}\mu_{\rm th} &\equiv m_{\rm th}(z_i)-M\\ &=5\log_{10}(D_L(z))\\ &\quad+5\log_{10}\left(\frac{H_0^{-1}}{Mpc}\right)+25,\end{aligned} \quad (20)$$

where

$$D_L(z)=H_0 d_L(z)=(1+z)\int_0^z\frac{H_0{\rm d}z'}{H(z';\theta)}, \quad (21)$$

$\mu_{\rm obs}$ is given by supernova dataset, d_L is the luminosity distance, and Hubble parameter H is given by expression (15) according to the expression of function $f(z)$.

The Hubble parameter $H(z)$ depends on the differential age of the universe as a function of redshift z in the form

$$H(z)=-\frac{1}{1+z}\frac{{\rm d}z}{{\rm d}t}. \quad (22)$$

Therefore, the value of $H(z)$ can be directly measured through a determination of ${\rm d}z/{\rm d}t$. By using the differential ages of passively evolving galaxies from the GDDS[37] and archival data,[38] Simon *et al*[36] obtained nine values of $H(z)$ in a range of $0<z<1.8$. Using these data we can constrain cosmological models by minimizing

$$\chi^2_{\rm Hub}(H_0,\theta)=\sum_{i=1}^{N}\frac{[H_{\rm th}(z_i)-H_{\rm obs}(H_0,\theta,z_i)]^2}{\sigma^2_{{\rm obs};i}}, \quad (23)$$

where $H_{\rm th}$ is the predicted value for the Hubble parameter and can be given by expression (15), $H_{\rm obs}$ is the observed value, $\sigma^2_{{\rm obs};i}$ is the standard deviation measurement uncertainty. Then we can combine two datasets to constrain the model parameters θ by minimizing the total likelihood $\chi^2_{\rm total}$

$$\chi^2_{\rm total}(H_0,\theta)=\chi^2_{\rm 192SNe}(H_0,\theta)+\chi^2_{\rm Hub}(H_0,\theta). \quad (24)$$

In the standard universe, a parametrized deceleration parameter $q(z)$, expressed in different forms, is often used to describe the evolution of accelerating universe, such as $q(z)=q_0+q_1z$,[48] $q(z)=q_0+\frac{q_1z}{(1+z)}$,[49] $q(z)=\frac{1}{2}+\frac{q_1+q_2z}{(1+z)^2}$,[50] and $q(z)=q_1+\frac{q_2}{1+\ln(1+z)}$.[49] The parameters q_0 and q_1, or, q_1 and q_2 are obtained by the best fitting estimations from cosmic observational datasets. In the framework of the 5D bounce universe, from expression (14) it is shown that function $f(z)$ can be integrated from a concrete form of $q(z)$. Once the function $f(z)$ is constructed, the evolutions of cosmological quantities can be obtained by expressions (16)–(18). As an example, in the present paper we consider a deceleration parameter $q(z)=q_1+\frac{q_2}{1+\ln(1+z)}$. According to expression (14), function $f(z)$ can be derived as

$$f(z)=(1+z)^{-2q_1}(1+\ln(1+z))^{-2q_2}. \quad (25)$$

Then, using expression (15) we obtain an expression of the Hubble parameter $H(z)$.

On the basis of expression (15), we can use the maximum likelihood method for expression (24) to constrain parameters $(H_0,\ q_1,\ q_2)$. Here, it should be noticed that since we are interested in the model parameters $(q_1,\ q_2)$, the H_0 contained in $\chi^2_{\rm total}(H_0,\theta)$ is a nuisance parameter and will be marginalized by integrating the likelihood $L(\theta)=\int {\rm d}H_0 P(H_0)\exp(-\chi^2(H_0,\theta)/2)$, where $P(H_0)$ is the prior distribution function of the present Hubble constant, and a Gaussian prior $H_0 = 72 \pm 8\,{\rm km S^{-1}\,Mpc^{-1}}$[51] is adopted in this paper. So, by using the maximum likelihood method to minimize the quantity $\chi^2_{\rm total}$, we obtain the best fitting model parameters $q_1 = 1.50$ and $q_2 = -2.26$ with $\chi^2_{\rm min} = 205.30$. Furthermore, according to expression (14), figure 1 shows the 1σ confidence level of the best fitting $q(z)$ calculated by using the covariance matrix, and the 1σ contour of parameters (q_1, q_2) for the combined constraint from the 192 ESSENCE SNe Ia data and the observational $H(z)$ data. From Fig.1(a), it can be seen that the evolution of q with respect to redshift z describes the current accelerating expansion of universe and the decelerating expansion in the past, and the best constraint on $q(z)$ from these two observations lies in a redshift range $z \approx 0.2 - 0.4$. Also, we can see that the best fitting values of transition redshift from decelerated expansion to accelerated expansion, z_T, and current deceleration parameter, q_0, are $z_T = 0.65^{+0.25}_{-0.12}$ and $q_0 = -0.76^{+0.15}_{-0.15}(1\sigma)$. And the 1σ confidence level of model parameters (q_1, q_2) are $q_1 = 1.50^{+0.79}_{-0.77}$ and $q_2 = -2.26^{+0.99}_{-0.98}$.

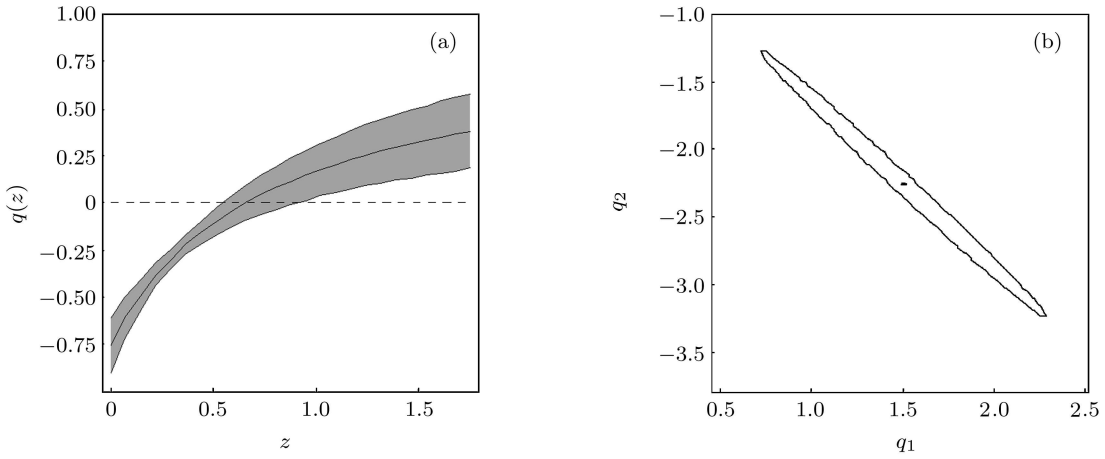


Fig.1. The best fitting forms of $q(z)$ and 1σ (indicated as shaded region) contour of parameters (q_1, q_2), which are constrained from the 192 ESSENCE SNe Ia data and the 9 observational $H(z)$ data.

Finally, using the best fitting values of model parameters $q_1 = 1.50$ and $q_2 = -2.26$ and assuming $\Omega_{0m} = 0.27$,[34] we plot the evolutions of dimensionless density parameters Ω_m, $\Omega_{\rm de}$, and EOS of DE $w_{\rm de}$ with respect to the redshift z according to expressions (16)–(18) (see Fig.2). From Fig.2 it can be seen that the evolution of $w_{\rm de}$ can cross over -1 at about $z = 0.23$ and the current value $w_{0\rm de} = w_{\rm de}(z = 0) = -1.15 < -1$. Furthermore, we can see that the cosmological quantity Ω_m becomes larger and $\Omega_{\rm de}$ becomes smaller with the increase of redshift z, and they are equal at $z \approx 0.38$.

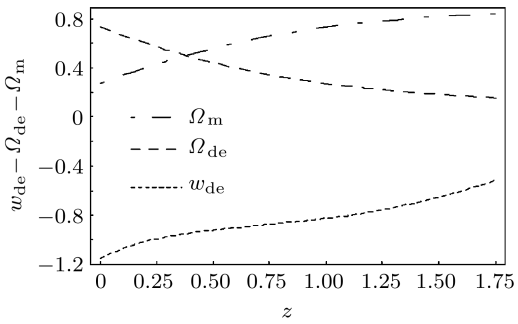


Fig.2. Variations of dimensionless density parameters $\Omega_{\rm m}$, $\Omega_{\rm de}$, and EOS of dark energy $w_{\rm de}$ with redshift z, where $q_1 = 1.50$ and $q_2 = -2.26$ are used according to the combined constraint.

3.2. Constraints on the accelerating universe by using a model-independent EOS of dark energy

From expression (16), it is easy to see that function $f(z)$ can be integrated according to a concrete form of $w_{\rm de}(z)$. Here we consider a model-independent EOS of DE

$$w_{\rm de} = \frac{1+z}{3}\frac{A_1 + 2A_2(1+z)}{A_1(1+z) + A_2(1+z)^2 + (1-\Omega_{0m}-A_1-A_2)} - 1.$$

According to this $w_{\rm de}(z)$, function $f(z)$ can be written as

$$f(z) = \frac{(1+z)^2}{\Omega_{0m}(1+z)^3 + (1-\Omega_{0m}) + A_1 z + 2A_2 z + A_2 z^2}. \tag{26}$$

Thus on the basis of function $f(z)$ (26), by using expressions (14) and (15) we use the recently observed data to constrain model parameters and plot the best fitting forms of deceleration parameter $q(z)$ with 1σ confidence level. To obtain significant constraints on cosmological quantities, here we combine 192 ESSENCE SNe Ia data with other four cosmic observations: the observational $H(z)$ data from the GDDS and archival data, the 3-year WMAP CMB shift parameter, the SDSS baryon acoustic peak and the x-ray gas mass fraction in clusters to constrain the DE model.

The structure of the anisotropy of the cosmic microwave background radiation depends on two eras in cosmology, i.e., last scattering and today. They can also be applied to restricting the model parameters of dark energy by using the shift parameter[52]

$$R = \sqrt{\Omega_{\rm om}}\int_0^{z_{\rm rec}} \frac{H_0 {\rm d}z'}{H(z';\theta)}, \tag{27}$$

where $z_{\rm rec} = 1089$ is the redshift of recombination, and $\Omega_{\rm om}$ is current value of the dimensionless matter density. R is obtained from the three-year WMAP data as[39]

$$R = 1.70 \pm 0.03. \tag{28}$$

From the CMB constraint, the best fitting values of parameters in the DE models can be determined by minimizing

$$\chi^2_{\rm CMB}(\theta) = \frac{(R(\theta) - 1.70)^2}{0.03^2}. \tag{29}$$

Because the universe has a fraction of baryons, the acoustic oscillations in the relativistic plasma would be imprinted on the late-time power spectrum of the nonrelativistic matter.[53] Therefore, the acoustic signatures in the large-scale clustering of galaxies can also serve as a test for constraining models of DE with the detection of a peak in the correlation function of luminous red galaxies in the SDSS.[40] By using the equation

$$A_{\rm BAO} = \sqrt{\Omega_{0m}}E(z_{\rm BAO})^{-1/3}\left[\frac{1}{z_{\rm BAO}}\int_0^z \frac{{\rm d}z'}{E(z';\theta)}\right]^{2/3}, \tag{30}$$

$A_{\rm BAO} = 0.469 \pm 0.017$ measured from the SDSS data, and $z_{\rm BAO} = 0.35$, we can minimize the $\chi^2_{\rm BAO}$ defined as[54]

$$\chi^2_{\rm BAO}(\theta) = \frac{(A_{\rm BAO}(\theta) - 0.469)^2}{0.017^2}. \tag{31}$$

The observations of x-ray gas mass fraction in galaxy clusters provide key information on the dark matter and the formation of structures in the universe, and they can be used to constrain the cosmological parameters.[55] It is assumed that the baryon gas mass fraction in clusters,[56,57]

$$f_{\rm gas} = \frac{M_{b-{\rm gas}}}{M_{\rm tot}}, \tag{32}$$

is constant, independent of redshift, and it is related to the global fraction of the universe Ω_b/Ω_{0m}. In the standard cold dark matter (SCDM) model, $f^{\rm SCDM}_{\rm gas}$ is[56]

$$f^{\rm SCDM}_{\rm gas} = \frac{b}{1+\alpha}\frac{\Omega_b}{\Omega_{0m}}\left(\frac{d^{\rm SCDM}_A(z)}{d_A(z)}\right)^{3/2}, \tag{33}$$

where d_A is the diameter distance which is related to d_L via $d_L(z) = (1+z)^2 d_A(z)$, the parameter b is a bias factor suggesting that the baryon fraction in cluster is slightly lower than in the universe as a whole, the parameter $\alpha \approx 0.19\sqrt{h}$ is the ratio factor of optically luminous baryonic mass with x-ray gas contained in clusters. From the Cluster Baryon Fraction (CBF),

the best fitting values of parameters in cosmological models can be determined by minimizing[56]

$$\chi^2_{\rm CBF}(\theta) = N - \frac{M^2}{L}, \tag{34}$$

where

$$L = \sum_{i=1}^{N} \frac{\tilde{f}^{\rm SCDM}_{\rm gas}(z_i)^2}{\sigma^2_{f_{\rm gas},i}},$$

$$M = \sum_{i=1}^{N} \frac{\tilde{f}^{\rm SCDM}_{\rm gas}(z_i)\cdot f_{{\rm gas},i}}{\sigma^2_{f_{\rm gas},i}},$$

$$N = \sum_{i=1}^{N} \frac{\tilde{f}^2_{{\rm gas},i}}{\sigma^2_{f_{\rm gas},i}}, \tag{35}$$

and

$$\tilde{f}^{\rm SCDM}_{\rm gas}(z_i) = \left(\frac{d^{\rm SCDM}_A(z)}{d_A(z)}\right)^{3/2}, \tag{36}$$

$N = 26$ is the number of the observed $f_{{\rm gas},i}$, and $\sigma^2_{{\rm gas},i}$ is given in Ref.[41].

Table 1. The values of $\chi^2_{\rm min}$, best fitting model parameters, transition redshift z_T and current deceleration parameter q_0 obtained from two combined constraints.

data	$\chi^2_{\rm min}$	best fit model parameters	z_T	q_0
192 ESSENCE SNe +Hub+CMB+BAO+CBF	232.25	$\Omega_{0m} = 0.27^{+0.03}_{-0.03},\ A_1 = -0.63^{+0.24}_{-0.22},\ A_2 = 0.23^{+0.08}_{-0.08}$	$0.66^{+0.11}_{-0.08}$	$-0.69^{+0.10}_{-0.10}$
182 Gold SNe +Hub+CMB+BAO+CBF	197.18	$\Omega_{0m} = 0.28^{+0.04}_{-0.03},\ A_1 = -0.49^{+0.28}_{-0.25},\ A_2 = 0.24^{+0.09}_{-0.09}$	$0.60^{+0.11}_{-0.08}$	$-0.59^{+0.12}_{-0.12}$

Next, using the datasets of the above observational techniques, we minimize the total likelihood $\chi^2_{\rm total}$

$$\chi^2_{\rm total} = \chi^2_{\rm 192SNe} + \chi^2_{\rm Hub} + \chi^2_{\rm CMB} + \chi^2_{\rm BAO} + \chi^2_{\rm CBF}. \tag{37}$$

On the basis of expression (15), where $f(z)$ is given by expression (26), we obtain the best fitting model parameters with its $\chi^2_{\rm min}$value by applying the maximum likelihood method to expression (37). The results are listed in Table 1. According to expression (14), we plot the best fitting form of $q(z)$ with 1σ confidence level in Fig.3(a) by using covariance matrix. From Fig.3(a), the best fitting values of transition redshift $z_T = 0.66^{+0.11}_{-0.08}$ and current deceleration parameter $q_0 = -0.69^{+0.10}_{-0.10}$ (1σ) can be obtained. Furthermore, replacing the 192 ESSENCE data with 182 Gold data in the combined constraint, we obtain the best fitting values of z_T and q_0 for this kind of combined constraint. And the results are listed in Table 1, too. From Table 1 we can see that the former combined analysis tends to bigger value of z_T and smaller value of q_0 than the latter one.

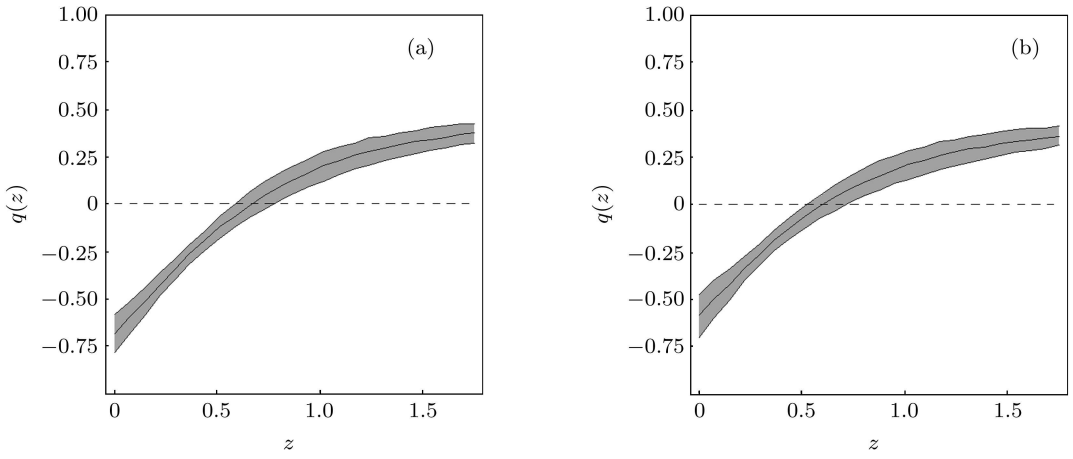


Fig.3. The best fitting forms of $q(z)$ with 1σ confidence level for the combined constraints from 192 ESSENCE SNe+Hub+CMB+BAO+CBF (a) and 182 Gold SNe+Hub+CMB+BAO+CBF (b), where 1σ confidence level is indicated as shaded region.

4. Conclusion

In the framework of a 5D bounce cosmological model we constrain the accelerating universe from recent cosmic observations. Concretely, a useful function $f(z)$ in the 5D bounce model is obtained by giving a concrete expression of deceleration parameter $q(z) = q_1 + \frac{q_2}{1+\ln(1+z)}$. Then the Hubble parameter $H(z)$ can be expressed by the function $f(z)$ in the bounce model. Thus on the basis of the obtained Hubble parameter $H(z)$ we constrain the accelerating universe from recently observed data: the 192 ESSENCE SNe Ia and the 9 observational $H(z)$ data. We obtain the best fitting model parameters $q_1 = 1.50^{+0.79}_{-0.77}$ and $q_2 = -2.26^{+0.99}_{-0.98}$ (1σ), and plot the best fitting forms of deceleration parameter $q(z)$ with 1σ confidence level in Fig.1(a) by using the covariance matrix. From Fig.1(a), it can be seen that the best fitting values of transition redshift z_T and current deceleration parameter q_0 are $z_T = 0.65^{+0.25}_{-0.12}$ and $q_0 = -0.76^{+0.15}_{-0.15}(1\sigma)$. And using the best fitting parameters $(q_1,\ q_2)$, we obtain the evolutions of dimensionless density parameters Ω_m, $\Omega_{\rm de}$, and EOS of DE $w_{\rm de}$ in the 5D bounce cosmological model. It is shown that the evolution of $w_{\rm de}$ crosses over -1 at about $z = 0.23$ and the current value $w_{0\rm de} = w_{\rm de}(z = 0) = -1.15 < -1$. Furthermore, by giving a concrete expression of model-independent EOS of DE $w_{\rm de}$, the useful function $f(z)$ in the 5D bounce model can also be obtained. Then using the maximum likelihood method we obtain the best fitting parameters from the recently observed data: the 192 ESSENCE SNe Ia, the observational $H(z)$ data, the 3-year WMAP, the SDSS baryon acoustic peak and the x-ray gas mass fraction in clusters. Next we plot the best fitting form of $q(z)$ with 1σ confidence level by using the covariance matrix. And the best fitting values of transition redshift z_T and current deceleration parameter q_0 are obtained according to Fig.3(a). The results are $z_T = 0.66^{+0.11}_{-0.08}$ and $q_0 = -0.69^{+0.10}_{-0.10}$ (1σ). Finally, comparing two combined constraints, i.e. replacing the 192 ESSENCE data with 182 Gold data in the combined analysis, we find that the constraint from the cosmic observations of 192 ESSENCE SNe+Hub+CMB+BAO+CBF tends to bigger value of transition redshift z_T, and smaller current value of deceleration parameter q_0 than the constraint from 182 Gold SNe+Hub+CMB+BAO+CBF.

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