Dark energy constraints in light of Pantheon SNe Ia, BAO, cosmic chronometers and CMB polarization and lensing data

Deng Wang[*]

Theoretical Physics Division, Chern Institute of Mathematics, Nankai University, Tianjin 300071, China

To explore whether there is new physics going beyond the standard cosmological model or not, we constrain seven cosmological models by combining the latest and largest Pantheon Type Ia supernovae sample with the data combination of baryonic acoustic oscillations, cosmic microwave background radiation, Planck lensing and cosmic chronometers. We find that a spatially flat universe is preferred in the framework of ΛCDM cosmology, that the constrained equation of state of dark energy is very consistent with the cosmological constant hypothesis in the ωCDM model, that there is no evidence of dynamical dark energy in the dark energy density-parametrization model, that there is no hint of interaction between dark matter and dark energy in the dark sector of the universe in the decaying vacuum model, and that there does not exist the sterile neutrino in the neutrino sector of the universe in the ΛCDM model. We also give the 95% upper limit of the total mass of three active neutrinos $\Sigma m_\nu < 0.178$ eV under the assumption of ΛCDM scenario. It is clear that there is no any departure from the standard cosmological model based on current observational datasets.

I. INTRODUCTION

With gradually mounting astronomical data and unceasingly improved statistical techniques, it is very promising for human beings to unveil the mysterious phenomena at cosmological scale in the near future. The main challenge of modern cosmology is to understand the nature of cosmic late-time acceleration, which has been confirmed by a large number of observations such as measurements of Type Ia supernovae (SNe Ia) distances [1,2], peaks of baryon acoustic oscillations (BAO) in the large-scale correlation function of galaxies [3], and the power spectrum of fluctuations in the cosmic microwave background (CMB) [4,5]. Most recently, on August 17, 2017 at 12:41:04 UTC, the first multimessenger gravitational-wave observation of a binary neutron star inspiral made by LIGO-Virgo detector network, once again, gives a convincing evidence that the universe is undergoing a phase of accelerated expansion [6,7]. Up to now, to describe this accelerated mechanism, theoretical physicists propose two main classes of models [8], i.e., the so-called dark energy (DE) and modified gravities. The former maintains the correctness of the general relativity (GR) and introduces an exotic matter source in the Einstein equation, while the latter modifies the standard Lagrangian of GR based on some reasonable physical consideration.

At present, in light of rich observed data, we just know several primary properties of DE: (i) a cosmic fluid with an equation of state (EoS) $\omega \approx -1$, which violates the strong energy condition; (ii) the DE fluid is homogeneously permeated in the universe and has no the property of clustering unlike the dark matter (DM). To characterize the DE phenomena, the simplest candidate is the standard cosmological model, i.e., the cosmological constant (Λ) plus cold DM (ΛCDM) scenario. This model can successfully explain various observations at both large and small scales. However, it faces at least two intractable problems, namely the coincidence and fine-tuning problems [9]. This indicates that the ΛCDM model may be not the underlying one governing the background evolution and large scale structure formation of the universe, and that it should be extended to a more complicated one or even replaced with another physical-driven scenario. Since the accelerated universe is discovered, there have been a great deal of DE models proposed by theoreticians to overcome the difficulties that ΛCDM meets in the last twenty years. With the endless data coming, it is more important for cosmologists to test the validity of some known and simple models rather than to develop new theoretical paradigms.

SNe Ia is a powerful geometrical distance indicator to probe the expansion history of the universe, particularly, the EoS of DE. During the past three years, the standard SNe Ia sample to constrain the cosmological models is the "joint light-curve analysis" (JLA) one constructed from Supernova Legacy Survey (SNLS) and Sloan Digital Sky Survey (SDSS), which consists of 740 data points covering the redshift range $0.01 < z < 1.3$ [10]. Most Recently, D. Scolnic *et al.* have reported a larger "Pantheon" SNe Ia

123507-1

sample than JLA one by combining the subset of 276 new Pan-STARRS1 (PS1) SNe Ia with useful distance estimates of SNe Ia from SNLS, SDSS, low-z and Hubble space telescope (HST) samples [11]. This sample consists of 1049 spectroscopically confirmed SNe Ia covering the redshift range $0.01 < z < 2.3$. In this work, our basic idea is to implement the DE constraints by using the latest and largest Pantheon SNe Ia sample to date. We obtain strict constraints on the parameters of seven cosmological models by combining the Pantheon data with the other four data sets.

This work is organized as follows. In the next section, we introduce seven cosmological models used in this analysis. In Sec. III, we describe the latest observational data sets and our analysis methodology. In Sec. IV, we exhibit the numerical analysis results. The conclusions are presented in the final section.

II. SEVEN COSMOLOGICAL MODELS

In this section, we introduce seven cosmological models to be constrained by using the astronomical data sets. Note that throughout this work, we investigate these seven models in a Friedmann-Robertson-Walker (FRW) universe in the framework of GR, and just concentrate on the late-time cosmology, consequently neglecting the contribution from radiation in the cosmic pie. Starting from the so-called Friedmann equations, we derive the corresponding dimensionless Hubble parameter (DHP) for the ΛCDM model as

$$E_1(z) = [\Omega_m(1+z)^3 + 1 - \Omega_m]^{\frac{1}{2}}, \qquad (1)$$

while for the nonflat ΛCDM (oΛCDM) model it is expressed as

$$E_2(z) = [\Omega_m(1+z)^3 + \Omega_K(1+z)^2 + 1 - \Omega_m - \Omega_K]^{\frac{1}{2}}, \qquad (2)$$

where Ω_m and Ω_K are present-day matter and curvature density parameters, respectively.

To achieve the goal of constraining the EoS of DE, we consider its simplest parametrization $\omega(z) = \omega$, i.e., the ωCDM model, where the DE is a single negative pressure fluid. The DHP for the spatially flat ωCDM model can be expressed as

$$E_3(z) = [\Omega_m(1+z)^3 + (1 - \Omega_m)(1+z)^{3(1+\omega)}]^{\frac{1}{2}}. \quad (3)$$

For a long time, an important topic in the field of modern cosmology is whether the DE evolves over time or not. To address this issue, we consider a DE density-parametrization (DEDP) model recently proposed by us [12], and its DHP is shown as

$$E_4(z) = \left[\Omega_m(1+z)^3 + (1-\Omega_m)\left(1+\beta-\frac{\beta}{1+z}\right)\right]^{\frac{1}{2}}, \qquad (4)$$

where β is the typical free parameter characterizing this parametrization model. It is easy to see that this model reduces to ΛCDM when $\beta = 0$, and that if β has any departure from zero, the DE will be dynamical.

Another important concern for cosmologists is whether or not there exists the interaction between DM and DE in the dark sector of the universe. To investigate this topic, we constrain an interesting decaying vacuum (DV) model proposed by Wang and Meng [13], and its DHP is written as

$$E_5(z) = \left[\frac{3\Omega_m}{3-\epsilon}(1+z)^{3-\epsilon} + 1 - \frac{3\Omega_m}{3-\epsilon}\right]^{\frac{1}{2}}, \qquad (5)$$

where ϵ denotes a free parameter of this DV model. It is worth noting that ϵ means a small modified matter expansion rate. $\epsilon < 0$ indicates that the momentum transfers from DM to DE and vice versa.

Based on our previous works [14–16], it is interesting to explore the neutrino physics in the framework of standard cosmological model using the latest Pantheon data. To weigh the total mass of three active neutrinos Σm_ν, we consider the ΛCDM plus a varying Σm_ν model ($\Lambda\nu$) by keeping the effective number of relativistic species $N_{\text{eff}} = 3.046$. In addition, we also explore the possibility of existence of massless sterile neutrinos by assuming $\Sigma m_\nu = 0.06$ eV with a degenerate mass hierarchy. For simplicity, We refer to this model as "Λs" hereafter.

Furthermore, we take the linear perturbations of background metric into account. As usual, the scalar mode perturbation of FRW spacetime is expressed as [17–19]

$$ds^2 = -(1 + 2\Phi)dt^2 + 2a\partial_i B dt dx$$
$$+ a^2[(1 - 2\Psi)\delta_{ij} + 2\partial_i\partial_j E]dx^i dx^j, \qquad (6)$$

where Φ and Ψ are the linear gravitational potentials. By use of the synchronous gauge $\Psi = \eta$, $\Phi = B = 0$ and $E = -(h + 6\eta)/2k^2$, the energy-momentum conservation equations of the cosmic fluids are written as [18]

$$\delta' = -3\left(\frac{\delta p}{\delta \rho} - \tilde{\omega}\right)\mathcal{H}\delta - (1 + \tilde{\omega})\left(\theta + \frac{h'}{2}\right), \qquad (7)$$

$$\theta' = \frac{\delta p}{\delta \rho}\frac{k^2\delta}{1+\tilde{\omega}} + (3\tilde{\omega} - 1)\mathcal{H}\theta - \frac{\tilde{\omega}'}{1+\tilde{\omega}'}\theta - k^2\delta, \quad (8)$$

where $\tilde{\omega}, \mathcal{H}, \sigma, \theta$ and δ are, respectively, the EoSs of cosmic fluids, conformal HP, shear, velocity perturbation and density perturbation, and the prime denotes the derivative with respect to the conformal time. Subsequently, the DE perturbations can be expressed as

$$\delta'_{de} = 3\mathcal{H}(\omega_{de} - c_s^2)\left[\delta_{de} + 3\mathcal{H}(1 + \omega_{de})\frac{\theta_{de}}{k^2}\right]$$
$$- 3\mathcal{H}\omega'_{de}\frac{\theta_{de}}{k^2} - (1 + \omega_{de})\left(\theta_{de} + \frac{h'}{2}\right), \quad (9)$$

$$\theta'_{de} = \frac{c_s^2}{1 + \omega_{de}}k^2\delta_{de} + (3c_s^2 - 1)\mathcal{H}\theta_{de}, \quad (10)$$

where ω_{de} and c_s^2 are the effective EoS of DE and the physical sound speed in the rest frame, respectively. In order to avoid the unphysical sound speed, we have used $c_s^2 = 1$ in the following analysis. At the same time, to calculate more smoothly, we also take $\sigma = 0$ numerically. Notice that the effective EoSs of DE of the ΛCDM, $o\Lambda$CDM, ωCDM, DEDP, DV, $\Lambda\nu$ and Λs models can be, respectively, expressed as $\omega_{de} = -1$, -1, ω, $-1 + \frac{\beta}{3[(1+\beta)(1+z)-\beta]}$ [12], $-1 + \frac{(1+z)^{3-\epsilon}-(1+z)^3}{\frac{3}{3-\epsilon}(1+z)^{3-\epsilon}-(1+z)^3+\frac{\Omega_\Lambda}{\Omega_m}}$ [13], -1 and -1, where $\tilde{\Omega}_\Lambda$ denotes the dimensionless ground state value of the vacuum.

III. OBSERVATIONAL DATA SETS AND ANALYSIS METHODOLOGY

In this section, we utilize the latest cosmological observations including the Pantheon SNe Ia sample to constrain the above models. The corresponding parameter spaces of these seven models can be shown as

$$\mathbf{P_1} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \ln(10^{10}A_s), n_s\}, \quad (11)$$

$$\mathbf{P_2} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \Omega_K, \ln(10^{10}A_s), n_s\}, \quad (12)$$

$$\mathbf{P_3} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \omega, \ln(10^{10}A_s), n_s\}, \quad (13)$$

$$\mathbf{P_4} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \beta, \ln(10^{10}A_s), n_s\}, \quad (14)$$

$$\mathbf{P_5} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \epsilon, \ln(10^{10}A_s), n_s\}, \quad (15)$$

$$\mathbf{P_6} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, \Sigma m_\nu, \ln(10^{10}A_s), n_s\}, \quad (16)$$

$$\mathbf{P_7} = \{\Omega_b h^2, \Omega_c h^2, 100\theta_{MC}, \tau, N_{eff}, \ln(10^{10}A_s), n_s\}, \quad (17)$$

where $\Omega_b h^2$ and $\Omega_c h^2$ are present-day baryon and CDM densities, θ_{MC} denotes the ratio between angular diameter distance and sound horizon at the redshift of last scattering z_{ls}, τ represents optical depth due to reionization, $\ln(10^{10}A_s)$ and n_s are the amplitude and spectral index of primordial power spectrum at the pivot scale $K_0 = 0.05$ Mpc^{-1}, Ω_K, ω, β and ϵ are typical parameters of $o\Lambda$CDM, ωCDM, DEDP and DV models, respectively. Here h is related to the Hubble constant H_0 by $H_0/h \equiv 100$ km s^{-1} Mpc^{-1}.

The cosmological observations used in this analysis can be summarized in the following manner:

SNe Ia: Testing the ability of the latest Pantheon SNe Ia sample in constraining the cosmological parameters is the key issue in this work. As described in the introduction, this sample integrates the PS1, SNLS, SDSS, low-z and HST data to form the largest SNe Ia sample up to now, which consists of 1049 spectroscopically confirmed SNe Ia lying in the range $0.01 < z < 2.3$. D. Scolnic *et al.* have made a new progress on reducing the photometric calibration uncertainties, which dominates the systematic error budget of every major analysis of cosmological parameters with SNe Ia for a long time, to the point where they are familiar in magnitude to other major sources of known systematic errors (see [11] for details). Hereafter we refer to this data set as "S".

CMB: We employ the CMB temperature and polarization data from the full Planck-2015 survey in our numerical analysis [20], which includes the likelihoods of Planck-2015 low-ℓ temperature and polarization likelihood at $2 \leq \ell \leq 29$, temperature (TT) at $30 \leq \ell \leq 2500$, cross-correlation of temperature and polarization (TE) and polarization (EE) power spectra. Hereafter we denote this data set as "C".

BAO: The BAO probe which is almost unaffected by uncertainties in the nonlinear evolution of matter density field and other systematic errors, is considered as the standard ruler to measure the evolution of the universe. To break the parameter degeneracies from other observations, here we use four BAO measurements: the 6dFGS sample at effective redshift $z_{eff} = 0.106$ [21], the SDSS-MGS one at $z_{eff} = 0.15$ [22], and the LOWZ at $z_{eff} = 0.32$ and CMASS at $z_{eff} = 0.57$ data from the SDSS-III BOSS DR12 sample [23]. This data set is denoted as "B".

Cosmic chronometers: We also employ the observations of cosmic expansion rate from cosmic chronometers (CC), which is independent of any cosmological theory. This data set is obtained by utilizing the most massive and passively evolving galaxies based on the "galaxy differential age." In this work, we use 30 CC data points to implement constraints on the above models [24,25]. We shall refer to this data set as "H".

Lensing: We also use the Planck-2015 lensing likelihood as a complementary probe to explore the evolution of the universe in this analysis [26]. It is noteworthy that Planck-2015 lensing data has given the most powerful measurement with a 2.5% constraint on the amplitude of the lensing potential power spectrum. We shall denote this data set as "L".

Using these observational data sets, we employ the Markov Chain Monte Carlo (MCMC) method to infer the posterior probability density distributions of different model parameters. Specifically, we modify carefully the November 2016 version of the publicly MCMC code COSMOMC [27], which obeys a convergence diagnostic

TABLE I. The 68% confidence intervals of different parameters of the ΛCDM, $o\Lambda$CDM, ωCDM, DEDP and DV models using the combined data sets SCBHL, respectively.

Model	ΛCDM	$o\Lambda$CDM	ωCDM	DEDP	DV
$\Omega_b h^2$	0.02241 ± 0.00013	0.02218 ± 0.00017	0.02233 ± 0.00015	0.02238 ± 0.00012	0.02244 ± 0.00014
$\Omega_c h^2$	0.11756 ± 0.00077	$0.11942^{+0.00067}_{-0.0013}$	0.1182 ± 0.0011	0.11766 ± 0.00070	0.11779 ± 0.00083
$100\theta_{MC}$	1.04111 ± 0.00028	1.04092 ± 0.00033	1.04097 ± 0.00030	1.04098 ± 0.00022	1.04106 ± 0.00029
τ	$0.0825^{+0.0017}_{-0.0027}$	$0.0849^{+0.0026}_{-0.0032}$	$0.078^{+0.012}_{-0.010}$	$0.0873^{+0.0051}_{-0.0046}$	0.0825 ± 0.0031
$\ln(10^{10}A_s)$	3.0967 ± 0.0035	$3.1005^{+0.0029}_{-0.0037}$	$3.070^{+0.024}_{-0.027}$	3.0971 ± 0.0060	$3.084^{+0.0130}_{-0.0076}$
n_s	0.9725 ± 0.0033	$0.9643^{+0.0059}_{-0.0029}$	0.9688 ± 0.0043	0.9707 ± 0.0030	$0.9719^{+0.0032}_{-0.0028}$
Ω_K	$\cdots$	0.0020 ± 0.0014	$\cdots$	$\cdots$	$\cdots$
ω	$\cdots$	$\cdots$	$-1.010^{+0.035}_{-0.031}$	$\cdots$	$\cdots$
β	$\cdots$	$\cdots$	$\cdots$	-0.0026 ± 0.0017	$\cdots$
ϵ	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$-0.00029^{+0.00028}_{-0.00025}$
H_0	68.31 ± 0.37	$68.41^{+0.88}_{-0.53}$	$68.26^{+0.75}_{-0.87}$	68.21 ± 0.28	68.33 ± 0.37
Ω_m	0.3013 ± 0.0046	$0.3040^{+0.0049}_{-0.0090}$	0.3031 ± 0.0074	0.3024 ± 0.0038	0.3018 ± 0.0048
σ_8	0.8266 ± 0.0031	$0.8341^{+0.0035}_{-0.0053}$	$0.8204^{+0.0102}_{-0.0122}$	0.8265 ± 0.0039	0.8219 ± 0.0052
$\chi^2_{\min}$	14051.17	14053.99	14051.68	14052.66	14049.42

based on the Gelman and Rubin statistic, and Boltzmann code CAMB [28]. To carry out the standard Bayesian analysis, we adopt the prior ranges for different model parameters as follows: $\Omega_b h^2 \in [0.005, 0.1]$, $\Omega_c h^2 \in [0.001, 0.99]$, $100\theta_{MC} \in [0.5, 10]$, $\tau \in [0.01, 0.8]$, $\ln(10^{10}A_s) \in [2, 4]$, $n_s \in [0.8, 1.2]$, $\Omega_K \in [-0.5, 0.5]$, $\omega \in [-3, 1]$, $\beta \in [-3, 3]$, $\epsilon \in [-0.3, 0.3]$, $\Sigma m_\nu \in [0, 5]$, $N_{\text{eff}} \in [3, 5]$. To exhibit better the ability of Pantheon sample in constraining seven cosmological models, firstly, we implement two kinds of constraints based on current data: (i) Pantheon alone (S); (ii) All data "SCBHL."

IV. ANALYSIS RESULTS

Utilizing the combined constraint from SCBHL, our MCMC results are exhibited in Table I. The 68% and 95% confidence regions of key parameter pairs of the ΛCDM, $o\Lambda$CDM, ωCDM, DEDP, DV, $\Lambda\nu$ and Λs models are also presented in Figs. 1–3, respectively. Combining the CBHL data sets with the Pantheon sample, it is very clear that the constraints on the parameters of ΛCDM, $o\Lambda$CDM and ωCDM models are improved in comparison with the results shown in [11] (see Tab. I). More specifically, using SCBHL, we obtain the following conclusions: (i) for $o\Lambda$CDM, the spatial curvature $\Omega_K = 0.0020 \pm 0.0014$ of the universe is compatible with zero at the 1.43σ confidence level (CL), which indicates that a spatially flat universe is preferred by current data in the framework of ΛCDM cosmology. Meanwhile, our result prefers a positive best-fitting value corresponding to an open universe and is in a good agreement with the Planck's restriction $|\Omega_K| < 0.005$ [20]; (ii) for ωCDM, the constrained EoS of DE $\omega = -1.010^{+0.035}_{-0.031}$ is consistent with the cosmological constant scenario and Planck's result $\omega = -1.006 \pm 0.045$ at the 1σ

CL [20]; (iii) for DEDP, the typical model parameter $\beta = -0.0026 \pm 0.0017$ is consistent with zero at the 1.53σ CL, which is very compatible with our previous result [12] and implies that there is no obvious evidence for dynamical DE; (iv) for DV, the constrained modified matter expansion rate $\epsilon = -0.00029^{+0.00028}_{-0.00025}$ just deviates very slightly from zero, which indicates that there is no obvious interaction between DM and DE in the dark sector of the universe at the 1.04σ CL; (v) for $\Lambda\nu$, the mass sum of three active neutrinos is constrained to $\Sigma m_\nu < 0.178$ eV at the 2σ CL, which is tighter than the Planck's constraint $\Sigma m_\nu < 0.23$ eV by using "Planck TT + lowP + lensing + ext" (see [20] for more details); (vi) for Λs, we give the 68% limits of the effective number of relativistic degrees of freedom $N_{\text{eff}} = 3.11 \pm 0.15$, which is compatible with the standard value $N_{\text{eff}} = 3.046$ of the standard model of particle physics at the 1σ CL and has a smaller error than Planck's restriction $N_{\text{eff}} = 3.15 \pm 0.23$ [20]. In Fig. 2,
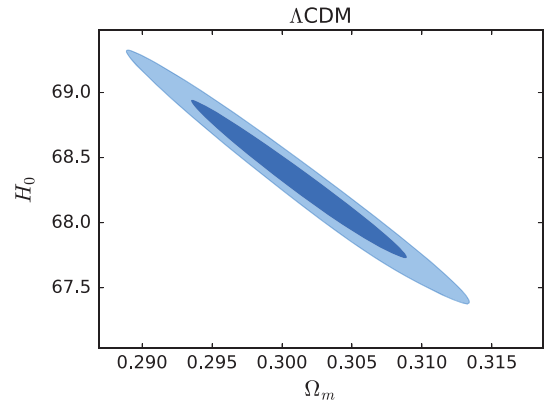

FIG. 1. The 68% and 95% confidence regions of the ΛCDM model using the combined data sets SCBHL are shown.
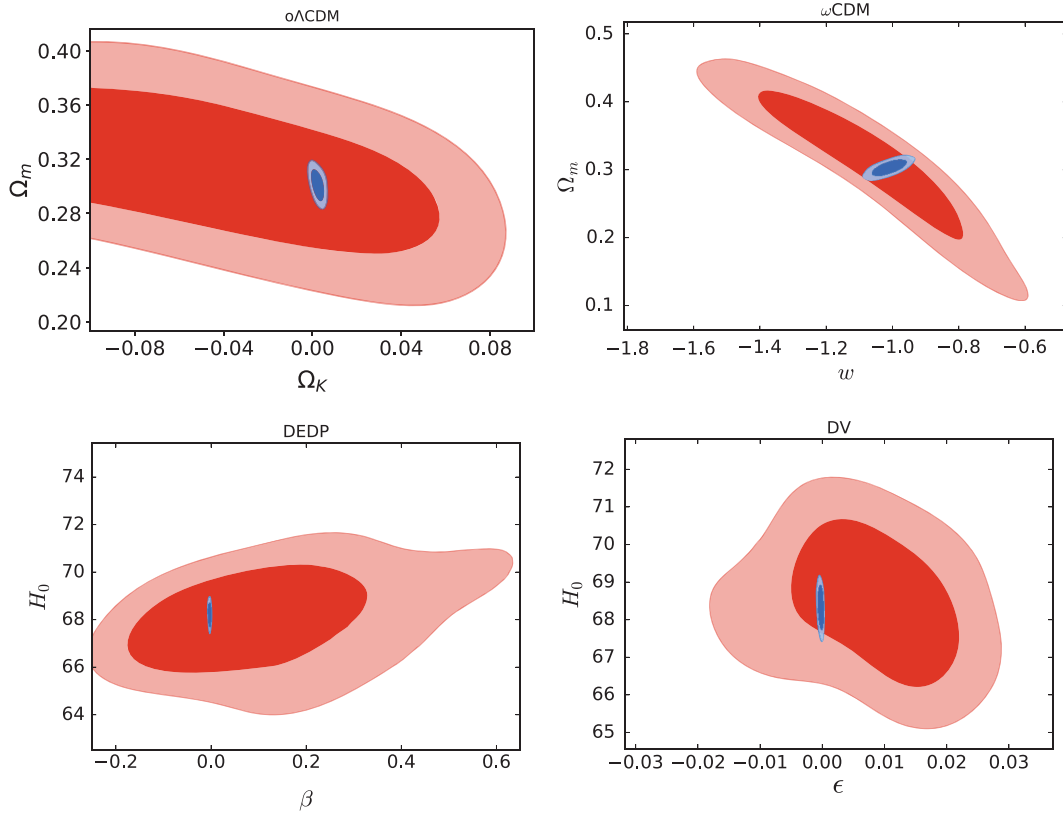
FIG. 2.   The 68% and 95% confidence regions of the $o\Lambda$CDM, ωCDM, DEDP and DV models using the Pantheon SNe Ia sample (red contours) and combined data sets SCBHL (blue contours) are shown, respectively.

one can also find that the constraints on the typical parameters Ω_K, ω, β and ϵ from SCBHL are much tighter than those from the Pantheon sample. By combining the Pantheon data set with CBHL, we find that the current H_0 tension between the directly local observation $H_0 = 73.24 \pm 1.74$ km s^{-1} Mpc^{-1} by Riess *et al.* [29] and the indirectly global derivation $H_0 = 66.93 \pm 0.62$ km s^{-1} Mpc^{-1} by Planck Collaboration [20] can be slightly alleviated from 3.4σ to 2.77σ, 2.48σ, 2.63σ, 2.85σ, 2.76σ, 2.85σ and 2.40σ for the ΛCDM, $o\Lambda$CDM, ωCDM, DEDP, DV, $\Lambda\nu$

and Λs models, respectively. Meanwhile, as Planck's prediction $n_s = 0.968 \pm 0.006$ [20], we find that the scale invariance of primordial power spectrum in the ΛCDM, $o\Lambda$CDM, ωCDM, DEDP, DV, $\Lambda\nu$ and Λs models is strongly excluded at the 8.33σ, 6.05σ, 7.26σ, 9.77σ, 8.33σ, 7.34σ and 5.15σ CL, respectively.

We also exhibit the MCMC results using the Pantheon sample to constrain cosmological models in Table II. We find that: (i) our constraints $\Omega_m = 0.297 \pm 0.024$ for ΛCDM, $\Omega_K = -0.058 \pm 0.121$ and $\Omega_m = 0.318 \pm 0.071$
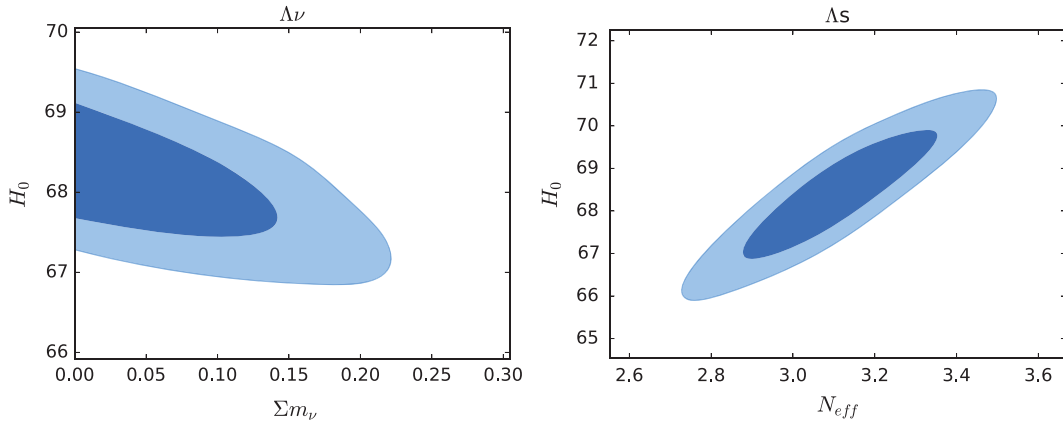

FIG. 3.   The 68% and 95% confidence regions of the $\Lambda\nu$ and Λs models using the combined data sets SCBHL are shown, respectively.

TABLE II.   The 68% confidence intervals of different parameters of the $o\Lambda$CDM, ωCDM, DEDP and DV models using the Pantheon SNe Ia sample, respectively.

Model	ΛCDM	$o\Lambda$CDM	ωCDM	DEDP	DV
Ω_m	0.297 ± 0.024	0.318 ± 0.071	$0.312^{+0.082}_{-0.058}$	0.305 ± 0.017	0.302 ± 0.021
Ω_K	$\cdots$	-0.058 ± 0.121	$\cdots$	$\cdots$	$\cdots$
ω	$\cdots$	$\cdots$	$-1.07^{+0.22}_{-0.20}$	$\cdots$	$\cdots$
β	$\cdots$	$\cdots$	$\cdots$	$0.10^{+0.12}_{-0.21}$	$\cdots$
ϵ	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$0.0079^{+0.0099}_{-0.0077}$
$\chi^2_{\min}$	1036.48	1036.74	1037.85	1036.64	1036.90

for $o\Lambda$CDM, and $\omega = -1.07^{+0.22}_{-0.20}$ and $\Omega_m = 0.312^{+0.082}_{-0.058}$ for ωCDM are well consistent with those presented in [11]; (ii) using only Pantheon data, the constrained parameters $\beta = 0.10^{+0.12}_{-0.21}$ for DEDP and $\epsilon = 0.0079^{+0.0099}_{-0.0077}$ for DV imply that there is still no evidence of dynamical DE at the 1σ CL and no interaction between DM and DE in the dark sector of the universe at the 1.03σ CL, respectively; (iii) the constraints $\omega = -1.010^{+0.035}_{-0.031}$ for ωCDM and $\epsilon = -0.00029^{+0.00028}_{-0.00025}$ for DV, and $\beta = -0.0026 \pm 0.0017$ for DEDP using SCBHL are more accurate than those using only Pantheon sample by one and two orders of magnitudes, respectively; (iv) very interestingly, for $o\Lambda$CDM, our result $\Omega_K = -0.058 \pm 0.121$ from SNe Ia data prefers a negative best-fitting value corresponding to a closed universe, which is different from the case of SCBHL (see also Tables I–II).

V. DISCUSSIONS AND CONCLUSIONS

Based on the most recent work that releases the largest Pantheon SNe Ia sample to date [11], our motivation is to test the ability of the Pantheon SNe Ia in constraining cosmological models, implement strict constraints using the data combination SCBHL and investigate whether there is new physics beyond the standard cosmological model.

Using the combined datesets SCBHL, we find that: (i) a spatially flat universe is supported in the framework of ΛCDM cosmology; (ii) the constrained EoS of DE is very consistent with the cosmological constant scenario at the 1σ CL in the ωCDM model; (iii) there does not exist the dynamical DE by constraining the DEDP model we recently proposed; (iv) there is no interaction between DM and DE in the dark sector of the universe in the DV model; (v) there is no obvious hint of sterile neutrinos in the neutrino sector of the universe under the assumption of ωCDM model; (vi) the H_0 tension between the directly

local observation by Riess *et al.* [29] and the indirectly global derivation by Planck Collaboration [20] can be moderately relieved in all seven models.

It is noteworthy that we obtain improved constraints on neutrino parameters Σm_ν and $N_{\rm eff}$ by adding two updated BAO data points from BOSS DR12 sample [23], CMB TT and EE likelihoods and cosmic chronometers into the Planck's analysis [20]. The effects of the improvements can be mainly attributed to the addition of two updated BAO points and CMB TT and EE likelihoods. Other than the data used in [11], we switch one old BAO point for two newer BAO ones, and also use CMB TT and EE likelihoods, Planck lensing data and cosmic chronometers to constrain the above cosmological models and obtain our better constraints on different cosmological parameters.

Since the constraint on the mass sum of three active neutrinos $\Sigma m_\nu < 0.178$ eV we give is tighter than the mass range $\Sigma m_\nu < 0.23$ eV preferred by the Planck Collaboration [20], the direct detection of nonrelativistic cosmic neutrinos with first generation experiment such as the PTOLEMY would be very difficult [30–32].

It is clear that we do not find any departure from the ΛCDM model based on current data. However, in theory, there is still a lack of deep understandings about the nature of DE. In the future, we hope to indicate the theoretical direction from the view of cosmological data analysis.

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