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Examining the cosmic acceleration with the latest Union2 supernova data

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ABSTRACT

In this Letter, by reconstructing the *Om* diagnostic and the deceleration parameter q from the latest Union2 Type Ia Supernova sample with and without the systematic error along with the baryon acoustic oscillation (BAO) and the cosmic microwave background (CMB), we study the cosmic expanding history, using the Chevallier–Polarski–Linder (CPL) parametrization. We obtain that Union2 + BAO favor an expansion with a decreasing of the acceleration at $z < 0.3$. However, once the CMB data is added in the analysis, the cosmic acceleration is found to be still increasing, indicating a tension between low redshift data and high redshift. In order to reduce this tension significantly, two different methods are considered and thus two different subsamples of Union2 are selected. We then find that two different subsamples + BAO + CMB give completely different results on the cosmic expanding history when the systematic error is ignored, with one suggesting a decreasing cosmic acceleration, the other just the opposite, although both of them alone with BAO support that the cosmic acceleration is slowing down. However, once the systematic error is considered, two different subsamples of Union2 along with BAO and CMB all favor an increasing of the present cosmic acceleration. Therefore a clear-cut answer on whether the cosmic acceleration is slowing down calls for more consistent data and more reliable methods to analyze them.

1. Introduction

The fact that our Universe has entered a state of accelerating expansion at redshifts less than ∼0.5 is well established by various independent observational data, including the Type Ia Supernova (SNIa) [1], the large scale structure [2,3], the cosmic microwave background (CMB) radiation [4], and so on. In order to explain this observed phenomena, one usually assumes that there exists, in our Universe, an exotic energy component, named dark energy (DE), which has negative pressure and thus can generate a repulsive force. It dominates our Universe and drives it to an accelerating expansion at recent times. Since the equation of state (EOS) w of dark energy embodies its properties, one may adopt a parametrized form of $w(z)$ with several free parameters, such as the Chevallier–Polarski–Linder (CPL) parametrization [5], to probe the cosmic expanding history and the evolutionary behavior of dark energy from observations.

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However, the results are different, sometimes even contradictory, when different observational data are used. For example, by investigating the diagnostic *Om* [6], which is defined as

$$Om(z) \equiv \frac{E^2(z)-1}{(1+z)^3-1}, \qquad E(z) = H(z)/H_0, \tag{1}$$

and the deceleration parameter q from the Constitution SNIa [7] along with the baryonic acoustic oscillation (BAO) distance ratio data [8,9] and using the CPL parametrization, Shafieloo et al. [10] found that the cosmic expansion acceleration might be slowing down, which is different from studies with other SNIa data sets [11]. However, once the CMB data is included, their result turns out to be consistent with the ΛCDM model very well and the universe is undergoing an accelerating expansion with an increasing acceleration. So, there appears some tension between low redshift data (Constitution SNIa + BAO) and high redshift (CMB) one. Surprisingly, further analysis using a subsample (SNLS + ESSENCE + CfA) of the Constitution SNIa reveals that the outcome that the cosmic acceleration has been over the peak does not rely on whether the CMB data is added, and the tension between SNIa and CMB is reduced significantly. Actually, although previous SNIa data sets, such as Gold06 [12] and

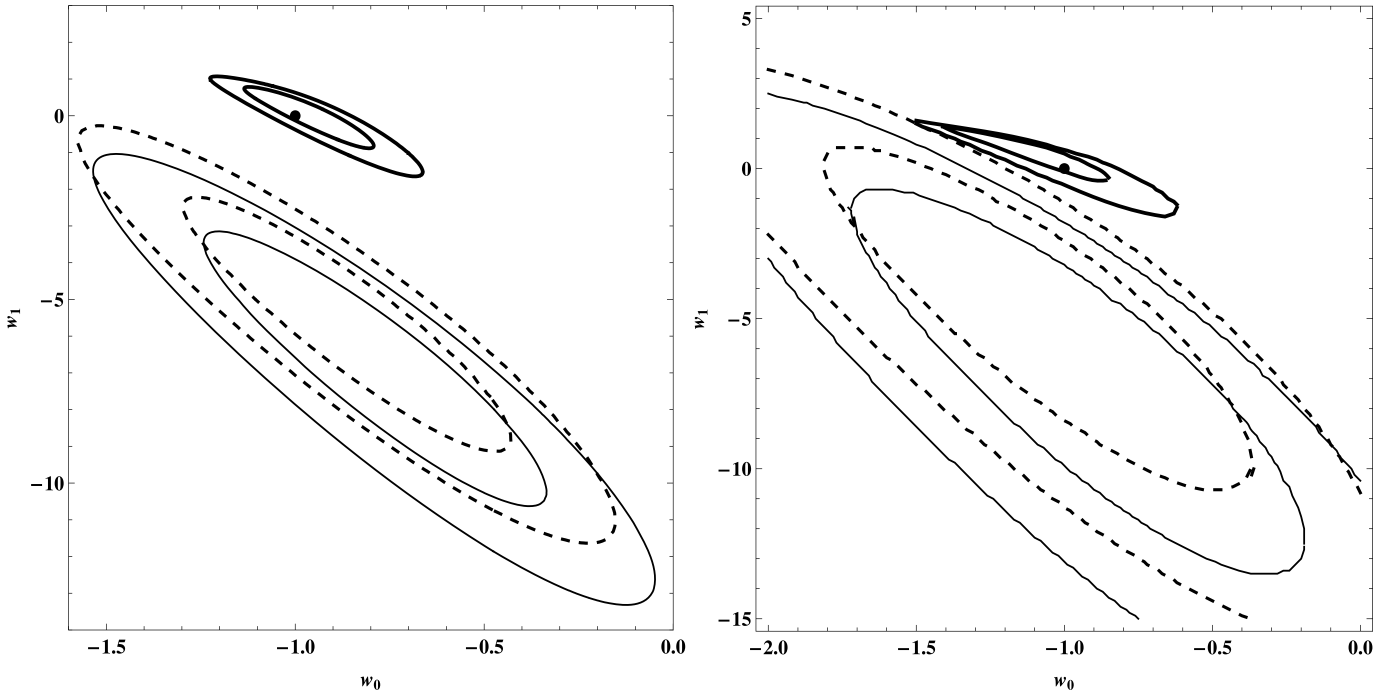

Fig. 1. The 68.3% and 95% confidence level regions for w_0 versus w_1. In the left panel, the system error in the SNIa is ignored, while in the right panel, it is considered. The dashed, solid and thick solid lines represent the results obtained from Union2, Union2 + BAO and Union2 + BAO + CMB, respectively. The point at $w_0 = -1$, $w_1 = 0$ represents the spatially flat ΛCDM model.

Union [13], do not support the result that the cosmic acceleration is slowing down, the tension between them and CMB has already been found [14,15], and in Ref. [15], Nesseris and Perivolaropoulos proposed a simple method to find the outliers responsible for it.

Recently, the largest and latest SNIa sample (Union2) was released by the Supernova Cosmology Project (SCP) Collaboration [16]. It consists of 557 data points. We list the subsets in detail in Table 1. In this Letter, we plan to reexamine the cosmic expanding history from the Union2, BAO and CMB by using the popular CPL parametrization. The tension between low redshift data and high redshift one is also analyzed in detail.

2. Observational data

For SNIa data, we use the latest Union2 compilation released by the Supernova Cosmology Project (SCP) Collaboration recently [16]. It consists of 557 data points and is the largest published SNIa sample up to now. The statistics of each subset with 3σ outlier rejection are detailed in Table 1. We fit the SNIa with cosmological models by minimizing the χ^2 value of the distance modulus

$$\chi^2 = \sum_{i,j=1}^{557} \left[\mu(z_i) - \mu_{obs}(z_i)\right] C_{sn}^{-1}(z_i, z_j) \left[\mu(z_j) - \mu_{obs}(z_j)\right], \quad (2)$$

where $\mu(z) \equiv 5\log_{10}[d_L(z)/Mpc] + 25$ is the theoretical value of the distance modulus, μ_{obs} is the corresponding observed one, and $C_{sn}(z_i, z_j)$ is the covariance matrix, which was detailed in Ref. [16] and can be found on the web site.[1] In the present Letter, we will use two different covariance matrices, which correspond to the cases with and without systematic error, respectively. The luminosity distance $d_L(z)$ is

$$d_L(z) = \frac{1+z}{H_0} \int_0^z \frac{dz'}{E(z')}. \quad (3)$$

Table 1
Statistics of each subset with 3σ outlier rejection for Union2 compilation. The Union2S consists of the underlined subsets.

Set	$\sigma_{cut} = 3$		
	N	σ_{sys}(68%)	RMS(68%)
Hamuy et al. (1996) [18]	18	$0.15^{+0.05}_{-0.03}$	$0.17^{+0.03}_{-0.03}$
Krisciunas et al. (2005) [19]	6	$0.04^{+0.13}_{-0.04}$	$0.11^{+0.03}_{-0.03}$
Riess et al. (1999) [20]	11	$0.15^{+0.07}_{-0.03}$	$0.17^{+0.03}_{-0.04}$
Jha et al. (2006) [21]	15	$0.21^{+0.07}_{-0.04}$	$0.22^{+0.04}_{-0.04}$
Kowalski et al. (2008) [22]	8	$0.07^{+0.09}_{-0.06}$	$0.15^{+0.03}_{-0.04}$
Hicken et al. (2009) [7]	102	$0.15^{+0.02}_{-0.01}$	$0.19^{+0.01}_{-0.01}$
Holtzman et al. (2009) [23]	129	$0.10^{+0.01}_{-0.01}$	$0.15^{+0.01}_{-0.01}$
Riess et al. (1998) + HZT [1]	11	$0.31^{+0.19}_{-0.09}$	$0.52^{+0.10}_{-0.12}$
Perlmutter et al. (1999) [1]	33	$0.41^{+0.12}_{-0.09}$	$0.64^{+0.07}_{-0.08}$
Barris et al. (2004) [24]	19	$0.18^{+0.13}_{-0.10}$	$0.38^{+0.06}_{-0.07}$
Amanullah et al. (2008) [25]	5	$0.19^{+0.21}_{-0.06}$	$0.21^{+0.05}_{-0.07}$
Knop et al. (2003) [26]	11	$0.05^{+0.10}_{-0.05}$	$0.15^{+0.03}_{-0.02}$
Astier et al. (2006) [27]	72	$0.13^{+0.03}_{-0.02}$	$0.21^{+0.02}_{-0.02}$
Miknaitis et al. (2007) [28]	74	$0.19^{+0.04}_{-0.03}$	$0.29^{+0.02}_{-0.02}$
Tonry et al. (2003) [29]	6	$0.15^{+0.21}_{-0.12}$	$0.23^{+0.05}_{-0.07}$
Riess et al. (2007) [30]	31	$0.16^{+0.06}_{-0.05}$	$0.45^{+0.05}_{-0.06}$
Amanullah et al. (2010) [16]	6	$0.00^{+0.00}_{-0.00}$	$0.00^{+0.00}_{-0.00}$
Total	557		

[1] http://supernova.lbl.gov/Union/.

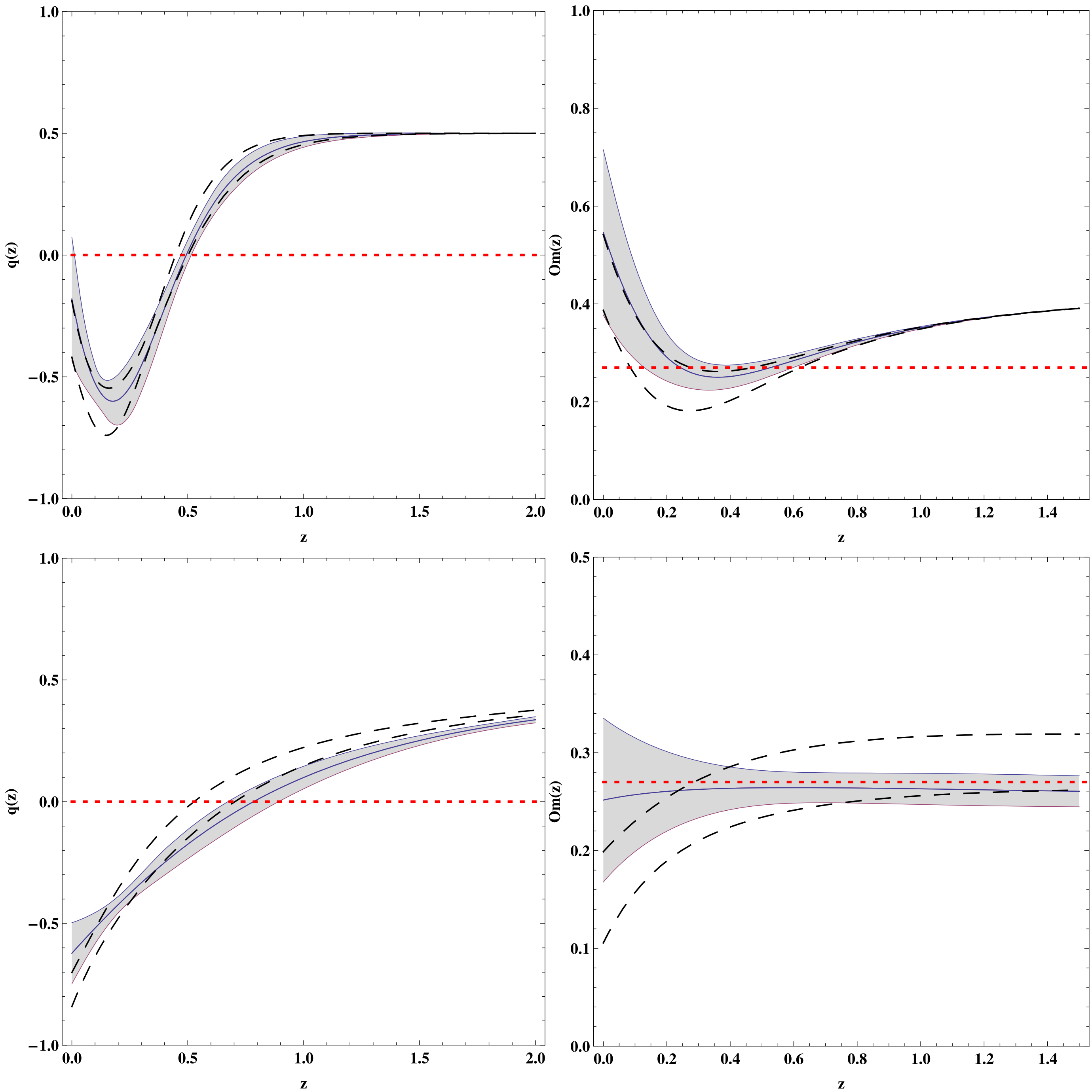

Fig. 2. The evolutionary behaviors of $q(z)$ and $Om(z)$ at the 68.3% confidence level. The gray regions and the regions between two long dashed lines show the results without and with the systematic errors in the SNIa, respectively. The upper and lower panels represent the results reconstructed from Union2 + BAO and Union2 + BAO + CMB, respectively.

For the CPL parametrization, $w = w_0 + w_1 \frac{z}{1+z}$,

$$E^2(z) = \Omega_{0m}(1+z)^3 + (1-\Omega_{0m})(1+z)^{3(1+w_0+w_1)} \exp\left(-\frac{3w_1 z}{1+z}\right), \qquad (4)$$

where Ω_{0m} is the present dimensionless density parameter of matter.

Since H_0 is a nuisance parameter, we marginalize over it by minimizing the following expression

$$\chi^2_{SNIa} = \sum_{i,j=1}^{557} \alpha_i C_{sn}^{-1}(z_i, z_j)\alpha_j - \frac{[\sum_{ij} \alpha_i C_{sn}^{-1}(z_i, z_j) - \ln 10/5]^2}{\sum_{ij} C_{sn}^{-1}(z_i, z_j)} - 2\ln\left(\frac{\ln 10}{5}\sqrt{\frac{2\pi}{\sum_{ij} C_{sn}^{-1}(z_i, z_j)}}\right), \qquad (5)$$

to obtain the constraint from SNIa, where $\alpha_i = \mu_{obs} - 25 - 5\log_{10}[H_0 d_L(z_i)]$.

The BAO data considered in our analysis is the distance ratio obtained at $z = 0.20$ and $z = 0.35$ from the joint analysis of the

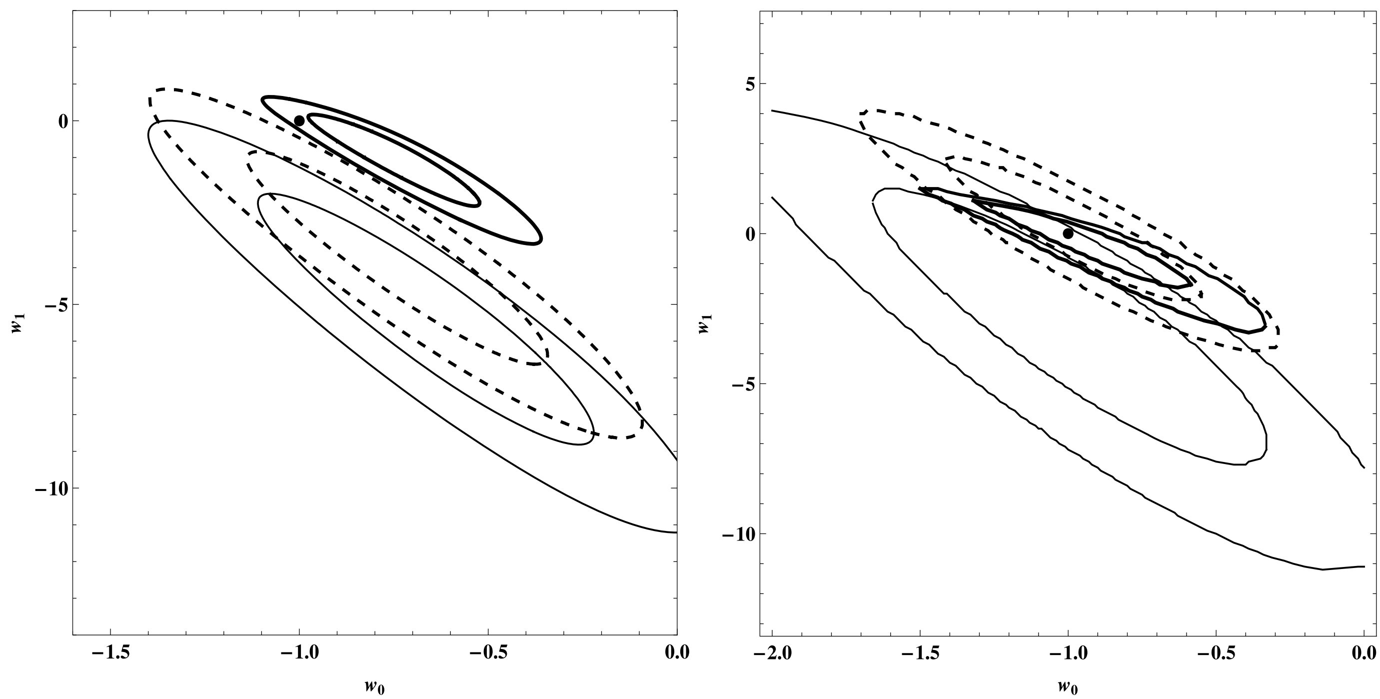

Fig. 3. The 68.3% and 95% confidence level regions for w_0 versus w_1. A subsample (Union2S) of Union2 obtained with the method in [10] is considered. In the left panel, the system error in the SNIa is ignored, while in the right panel, it is considered. The dashed, solid and thick solid lines represent the results obtained from Union2S, Union2S + BAO and Union2S + BAO + CMB, respectively. The point at $w_0 = -1$, $w_1 = 0$ represents the spatially flat ΛCDM model.

2dF Galaxy Redsihft Survey and SDSS data [9], which is a relatively model independent quantity and can be expressed as

$$\frac{D_V(z=0.35)}{D_V(z=0.20)} = 1.736 \pm 0.065, \tag{6}$$

with

$$D_V(z_{BAO}) = \left[\frac{z_{BAO}}{H(z_{BAO})} \left(\int_0^{z_{BAO}} \frac{dz}{H(z)} \right)^2 \right]^{1/3}. \tag{7}$$

Performing χ^2 statistics as follows

$$\chi^2_{BAO} = \frac{[D_V(z=0.35)/D_V(z=0.20) - 1.736]^2}{0.065^2}, \tag{8}$$

one can obtain the constraint from BAO. A result from the combination of SNIa and BAO is given by calculating $\chi^2_{SNIa} + \chi^2_{BAO}$.

Furthermore, in our analysis we add the CMB redshift parameter [17], which is the reduce distance at $z_{ls} = 1090$

$$R = \sqrt{\Omega_{0m}} \int_0^{z_{ls}} \frac{dz}{E(z)} = 1.71 \pm 0.019. \tag{9}$$

We also apply the χ^2

$$\chi^2_{CMB} = \frac{[R - 1.71]^2}{0.019^2}, \tag{10}$$

to find out the result from CMB and the constraints from SNIa + BAO + CMB are given by $\chi^2_{SNIa} + \chi^2_{BAO} + \chi^2_{CMB}$.

3. Results

We first investigate the constraints on model parameters and then analyze the evolutionary behavior of the decelerating parameter and $Om(z)$ to probe the properties of dark energy and the cosmic expanding history.

Fig. 1 shows the fitting contours of model parameters at the 68.3% and 95% confidence levels. In the left panel, the systematic error in the SNIa data is ignored, whereas in the right panel, it is considered. The dashed, solid and thick solid lines represent the results obtained from Union2, Union2 + BAO and Union2 + BAO + CMB, respectively. The point at $w_0 = -1$, $w_1 = 0$ denotes the spatially flat ΛCDM model. We find that, independent of whether the systematic error is taken into account, the outcome from Union2 is well consistent with that from Union2 + BAO, and both Union2 and Union2 + BAO exclude the spatially flat ΛCDM Universe at 95% confidence level. However, compared to the good overlap between regions from Union2 and Union2 + BAO, the one obtained from Union2 + BAO + CMB is relatively isolated and consistent with the ΛCDM, which means that there exists a tension between low redshift data and high redshift one. Obviously, if we use the SNIa with the systematic error, this tension is weaker than that from the SNIa without. That is, a consideration of systematic errors in the SNIa alleviates this tension markedly.

The evolutionary behaviors of $q(z)$ and $Om(z)$ at the 68.3% confidence level reconstructed from Union2 + BAO (upper panels) and Union2 + BAO + CMB (lower panels) are shown in Fig. 2. The gray regions and the regions between two long dashed lines represent the results without and with the systematic errors in the SNIa, respectively. It is easy to see that, for both the SNIa with systematic error and without, there is an apparent rise of the values of $Om(z)$ and $q(z)$ in redshifts $z < 0.3$ for Union2 + BAO (upper panels), which means that the cosmic acceleration is slowing down. However, this result changes dramatically with the addition of CMB in the analysis, as shown in the lower panels of Fig. 2, which still supports an expansion with an increasing acceleration. These results are the same as that derived from the Constitution SN Ia [10].

In order to reduce the tension between low redshift data and high redshift one, Shafieloo et al. [10] use a subsample of Constitution SNIa sample, which is obtained by excluding the Gold data, the high z Hubble Space Telescope data and older SNIa data sets

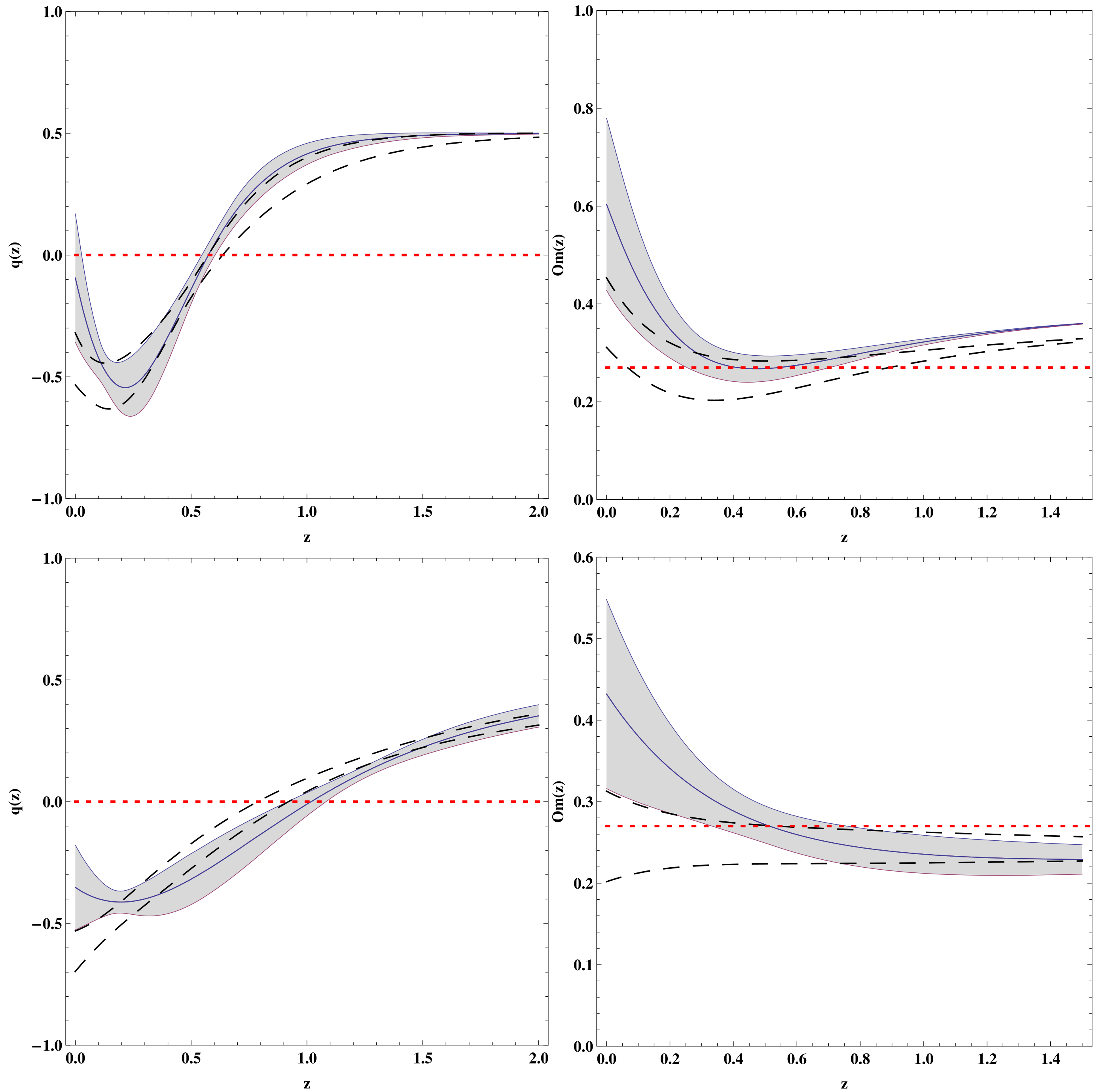

Fig. 4. The evolutionary behaviors of $q(z)$ and $Om(z)$ at the 68.3% confidence level. A subsample (Union2S) of Union2 obtained with the method in [10] is considered. The gray regions and the regions between two long dashed lines show the results without and with the systematic errors in the SNIa, respectively. The upper and lower panels represent the results reconstructed from Union2S + BAO and Union2S + BAO + CMB, respectively.

in Constitution and thus it consists only of SNLS, ESSENCE and CfA. They found that the tension is reduced significantly, the outcome does not rely on whether the CMB data is added and the cosmic acceleration has been over the peak. Here, we do a similar analysis as that in Ref. [10] by using a subsample of the Union2. This subsample, labeled as "Union2S", could be obtained by excluding the Gold data, the high z Hubble Space Telescope data and older SNIa data sets in the Union2. It contains 388 data points and is given in detail in Table 1 (underlined subsets). The fitting contours for $w_0 - w_1$ and reconstructed $q(z)$ and $Om(z)$ are shown in Figs. 3, 4, respectively. From Fig. 3, one can see that the tension between low redshift data and high redshift one is reduced noticeably, and the ΛCDM is consistent with Union2S with systematic error (Union2S(sys)) and Union2S(sys) + BAO + CMB at the 68% confidence level. The left panel of Fig. 4 shows that, for the case with the systematic error in the SNIa ignored, the evolution of $q(z)$ and $Om(z)$ reconstructed using Union2S + BAO is similar to that from Union2S + BAO + CMB. Both of them favor that the cosmic acceleration is slowing down. So, the same conclusion as that from the Constitution SNIa [10] is obtained. However, once the systematic error in the SNIa is considered, the results from Union2S(sys) + BAO + CMB show that the peak of $q(z)$ at $z < 0.3$

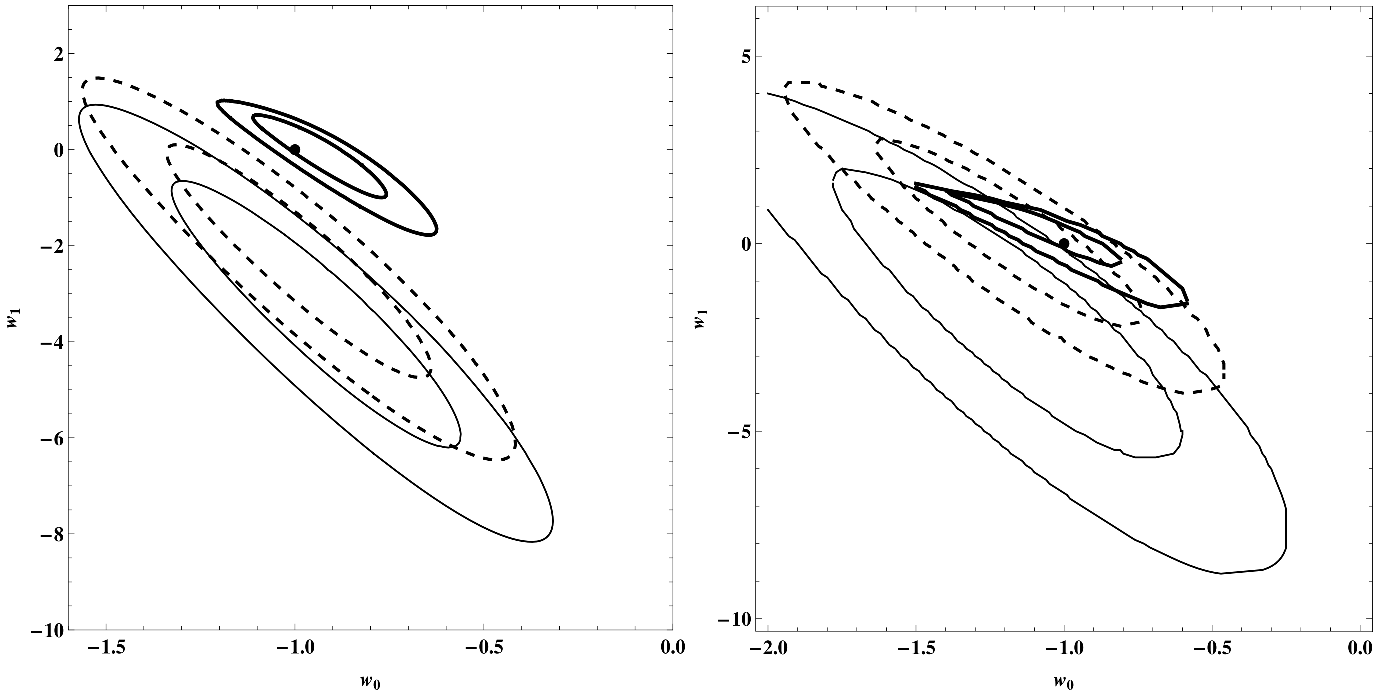

Fig. 5. The 68.3% and 95% confidence level regions for w_0 versus w_1. A subsample (Union2T) of Union2 obtained with the method in [15] is considered. In the left panel, the system error in the SNIa is ignored, while in the right panel, it is considered. The dashed, solid and thick solid lines represent the results obtained from Union2T, Union2T + BAO and Union2T + BAO + CMB, respectively. The point at $w_0 = -1$, $w_1 = 0$ represents the spatially flat ΛCDM model.

Table 2
The names of SNIa cut in the Union2 with the method in Ref. [15].

The subset (39 SNIa) cut in Union2
1998dx, 1999bm, 2001v, 2002bf, 2002hd, 2002hu, 2002jy, 2003ch, 2003ic, 2006br, 2006cm, 2006cz, 2007ca, 10106, 2005ll, 2005lp, 2005fp, 2005gs, 2005gr, 2005hv, 2005ig, 2005iu, 2005jj, 1997k, 2001jm, 1998ba, 03D4au, 04D3cp, 04D3oe, 03D4cx, 03D1co, d084, e140, f308, g050, g120, m138, 05Str, 2002fx

disappears, although Union2S(sys) + BAO still favor a slowing down of the present cosmic acceleration.

Let us now discuss another method in selecting a subsample of the SNIa data, which is based upon different considerations. This method was proposed by Nesseris and Perivolaropoulos [15] to find the outliers responsible for the tension in the SNIa data. In this method, a truncated version of the SNIa can be obtained by calculating the relative deviation to the best fit ΛCDM prediction and adopting a reasonable cut $|\mu_{obs} - \mu_{\Lambda\mathrm{CDM}}|/\sigma_{obs}$ beyond 1.9σ. Using this method, we find that 39 SNIa points distributed in the whole Union2 dataset should be discarded. The names of these 39 SNIa are listed in Table 2. Thus, there remain 518 data points and we call them "Union2T". The results from Union2T are shown Figs. 5, 6. We find, from Fig. 5, that the tension is also reduced significantly, and, the ΛCDM is consistent with Union2T(sys) and Union2T(sys) + BAO + CMB at the 68% confidence level. If the systematic error is ignored, the observation favors an expansion with an increasing acceleration at the present once the CMB is added, although Union2T + BAO still support that the cosmic acceleration is slowing down. This can been seen by looking at the grey regions in Fig. 6. This result is similar with that obtained from Union2, but is different from that from Union2S. However, once the systematic errors are considered in the SNIa, both Union2T(sys) + BAO and Union2T(sys) + BAO + CMB favor an expansion with an increasing acceleration at the present, which is different from that from Union2 and Union2S. In Table 3, we give the χ^2/dof (dof: degree of freedom) value of different datasets, from which, one can see that only in the case of Union2T is χ^2/dof significantly improved. That is, according to the χ^2/dof criterion, the method proposed in [15] is preferred.

4. Conclusion

In this Letter, we have examined the cosmic expanding history from the latest 558 Union2 SNIa together with BAO and CMB data. For the SNIa, the data with and without the systematic error are analyzed respectively. The popular CPL parametrization is considered. We first find that, independent of whether or not the systematic error is considered, there exists a tension between low redshift data (SNIa + BAO) and high redshift one (CMB), but for the case with the systematic error considered this tension is weaker than that from the SNIa without. By reconstructing the curves of $q(z)$ and $Om(z)$ from Union2 + BAO, we obtain that for both the SNIa with and without the systematic error the cosmic acceleration has already peaked at redshift $z \sim 0.3$ and is decreasing. However, when the CMB data is added in our analysis, this result changes dramatically and the observation favors a cosmic expansion with an increasing acceleration, which further confirms the existence of the tension.

In order to reduce this tension, two different methods given in Refs. [10,15] are considered. With the method in [10], we obtain a subsample of Union2 labeled as Union2S, which is given by excluding the Gold data, the high z Hubble Space Telescope data and the older SNIa data sets in Union2. Thus 388 data points are left in Union2S. Using Union2S, we find that the tension between SNIa + BAO and CMB is reduced markedly. For the case without the systematic error both Union2S + BAO and Union2S + BAO + CMB favor a decreasing of the cosmic acceleration at $z < 0.3$. However, once the systematic error is added, Union2S + BAO + CMB support a present increasing cosmicacceleration, although the result from Union2S + BAO is similar with the case without the systematic error. According to the method given in [15], we cut 39

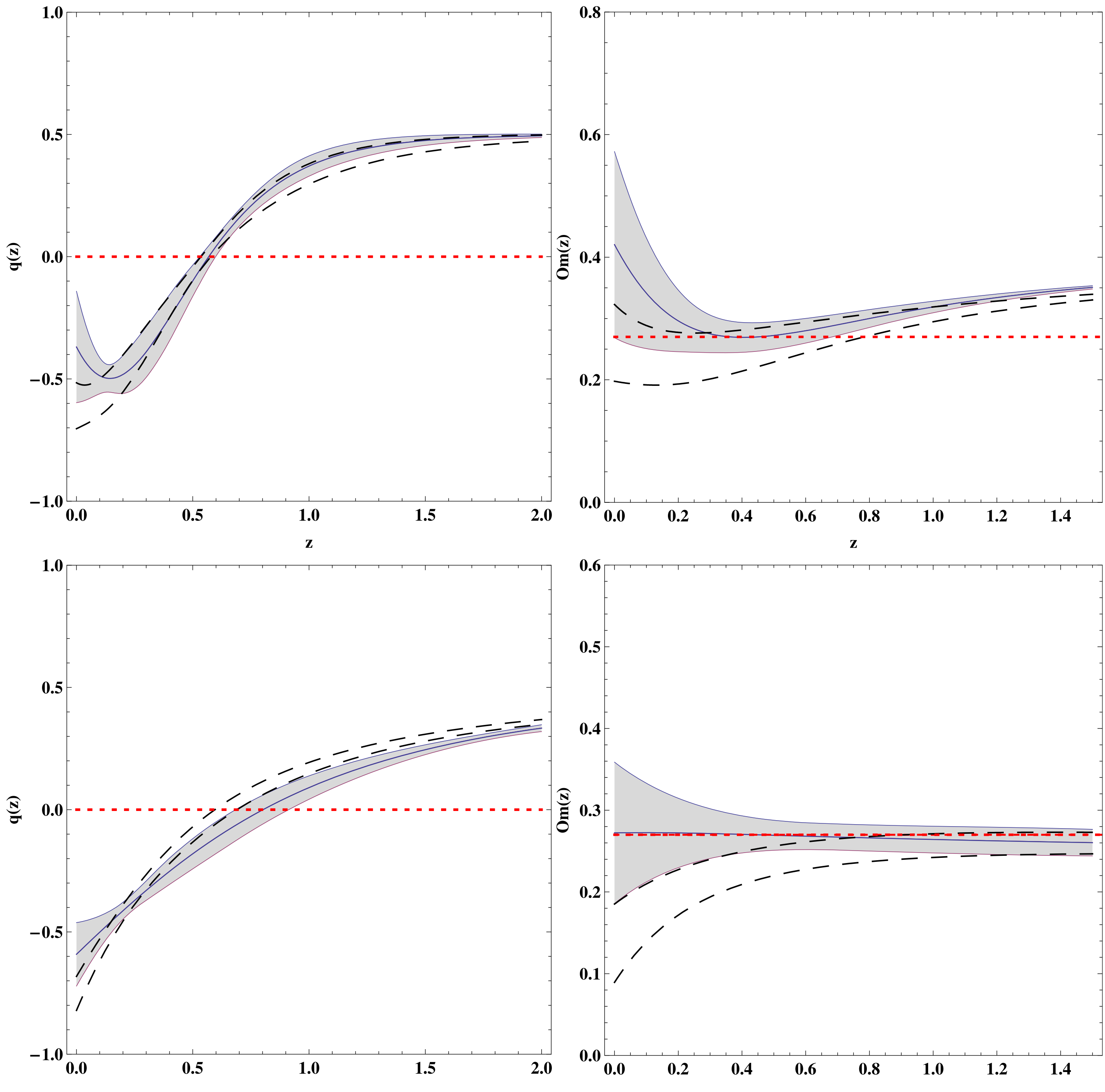

Fig. 6. The evolutionary behaviors of $q(z)$ and $Om(z)$ at the 68.3% confidence level. A subsample (Union2T) of Union2 obtained with the method in [15] is considered. The gray regions and the regions between two long dashed lines show the results without and with the systematic errors in the SNIa, respectively. The upper and lower panels represent the results reconstructed from Union2T + BAO and Union2T + BAO + CMB, respectively.

Table 3
Summary of the χ^2/dof from different data sets.

Dataset	χ^2/dof	Dataset	χ^2/dof
Union2 + BAO	0.962	Union2(sys) + BAO	0.938
Union2 + BAO + CMB	0.964	Union2(sys) + BAO + CMB	0.938
Union2S + BAO	0.956	Union2S(sys) + BAO	0.944
Union2S + BAO + CMB	0.955	Union2S(sys) + BAO + CMB	0.942
Union2T + BAO	0.653	Union2T(sys) + BAO	0.631
Union2T + BAO + CMB	0.653	Union2T(sys) + BAO + CMB	0.630

data points in Union2. Thus, a subsample (Union2T) containing 518 data points is obtained. With Union2T the tension is also reduced noticeably. However, when the systematic error is ignored, the results from reconstructing $q(z)$ and $Om(z)$ are similar to that given by Union2. Union2T + BAO favor that the accelerating expansion of the Universe is slowing down, while Union2T + BAO + CMB do not. If the systematic error is considered, both Union2T + BAO and Union2T + BAO + CMB support a present increasing cosmic acceleration. Therefore, when the systematic error in the SNIa is ignored, Union2S and Union2T give totally different results once the CMB is added, with one suggesting a slowing-down cosmic acceleration, the other just the opposite, although both of them can reduce the tension between low redshift data and high redshift one. If the systematic errors in the SNIa is considered, we find that the similar results are obtained from Union2S and Union2T. Both Union2S + BAO + CMB and Union2T + BAO + CMB support an increasing of the present cosmic acceleration. So, in order to have a clear-cut answer on whether the cosmic acceleration is slowing down or not, we still need to wait for more consistent data and more reliable methods to analyze them.

In Table 3, the values of χ^2/dof from different dataset are given. From which one can see that this value is significantly improved when Union2T is used. Thus, the χ^2_{Min}/dof criterion indicates that the method given in [15] is favored by observations.

Finally, we must point out that all our results obtained in the present Letter are based on the CPL parametrization. If one uses a different parameterization, as in Ref. [10], the results might change.

Acknowledgements

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References

[1] A.G. Riess, et al., Astron. J. 116 (1998) 1009;
S. Perlmutter, et al., Astron. J. 517 (1999) 565.
[2] D.J. Eisenstein, et al., Astron. J. 633 (2005) 560.
[3] M. Tegmark, et al., Phys. Rev. D 69 (2004) 103501.
[4] D.N. Spergel, et al., Astrophys. J. Suppl. 148 (2003) 175;
D.N. Spergel, et al., Astrophys. J. Suppl. 170 (2007) 377S.
[5] M. Chevallier, D. Polarski, Int. J. Mod. Phys. D 10 (2001) 213;
E.V. Linder, Phys. Rev. Lett. 90 (2003) 091301.
[6] V. Sahni, A. Shafieloo, A.A. Starobinsky, Phys. Rev. D 78 (2008) 103502.
[7] M. Hicken, et al., Astrophys. J. 700 (2009) 1097.
[8] W.J. Percival, et al., Mon. Not. R. Astron. Soc. 381 (2007) 1053.
[9] B.A. Reid, arXiv:0907.1659;
W.J. Percival, et al., arXiv:0907.1660.
[10] A. Shafieloo, V. Sahni, A.A. Starobinsky, Phys. Rev. D 80 (2009) 101301.
[11] Y.G. Gong, B. Wang, R.G. Cai, J. Cosmol. Astropart. Phys. 04 (2010) 019;
P. Wu, H. Yu, Phys. Lett. B 643 (2006) 315;
P. Wu, H. Yu, J. Cosmol. Astropart. Phys. 0802 (2008) 019.
[12] A.G. Riess, et al., Astrophys. J. 659 (2007) 98.
[13] M. Kowalski, et al., Astrophys. J. 686 (2008) 749.
[14] H.K. Jassal, J.S. Bagla, T. Padmanabhan, Phys. Rev. D 72 (2005) 103503;
H.K. Jassal, J.S. Bagla, T. Padmanabhan, arXiv:astro-ph/0601389;
S. Nesseris, L. Perivolaropoulos, Phys. Rev. D 72 (2005) 123519;
H. Wei, Phys. Lett. B 687 (2010) 286.
[15] S. Nesseris, L. Perivolaropoulos, J. Cosmol. Astropart. Phys. 0702 (2007) 025.
[16] R. Amanullah, et al., Astrophys. J. 716 (2010) 712.
[17] G. Hinshaw, et al., Astrophys. J. Suppl. Ser. 180 (2009) 225;
E. Kommatsu, et al., Astrophys. J. Suppl. Ser. 180 (2009) 230.
[18] M. Hamuy, et al., Astron. J. 112 (1996) 2398.
[19] K. Krisciunas, et al., Astron. J. 130 (2005) 2453.
[20] A.G. Riess, et al., Astron. J. 117 (1999) 707.
[21] S. Jha, et al., Astron. J. 131 (2006) 527.
[22] M. Kowalski, et al., Astrophys. J. 686 (2008) 749.
[23] J.A. Holtzman, et al., Astron. J. 136 (2008) 2306.
[24] B.J. Barris, et al., Astrophys. J. 602 (2004) 571.
[25] R. Amanullah, et al., A&A 486 (2008) 375.
[26] R.A. Knop, et al., Astrophys. J. 589 (2003) 102.
[27] P. Astier, et al., A&A 447 (2006) 31.
[28] G. Miknaitis, et al., Astrophys. J. 666 (2007) 674.
[29] J.L. Tonry, et al., Astrophys. J. 671 (2003) 1084.
[30] A.G. Riess, et al., Astrophys. J. 659 (2007) 98.