New data from DESI 2024 BAO measurements and their application in dark energy

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Full Text

Preamble

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Abstract

We obtain 5 new data from the DESI 2024 BAO measurements with the formula for the propagation of errors and apply them to investigate the nature of dark energy with a model-independent

method. We find that: (a) the universe may have an accelerated phase with a confidence level more than 5 σ during the period 0.51 < z < 0.93, (b) the equation of state of dark energy may be less than -1 with a confidence level exceeding 3.85 σ during the period 0.51 < z < 0.706.

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INTRODUCTION

Much number of independent cosmological observations had confirmed that the universe is currently undergoing an accelerated expansion. If assuming that general relativity (GR) holds, an unknown energy component, usually dubbed as dark energy (DE), must be introduced to explain this phenomenon. Cosmological constant with an equation of state (EoS) wx = px /ρx = -1 is the simplest and most theoretically sound scenario for DE. Adding in cold dark matter, this model (ΛCDM) is consistent with current astronomical observations.

However, it suffers from the cosmological constant problem [1] as well as the age problem [2]. Hubble tension may indicate that ΛCDM [3] faces new puzzles. Recently, the results of

the Dark Energy Spectroscopic Instrument (DESI) collaboration suggest that the DE may be dynamical [4–6].

The results from DESI Data Release 2 (DR2) are consistent with the ΛCDM model, but exhibit a 2.3 σ tension [6] with the cosmic microwave background (CMB) measurements which include Planck data and external CMB lensing data [7]. Combined with CMB temperature and polarization anisotropies, as well as CMB lensing, DESI DR2 data shows DDE is preferred at 3.1 σ by using the CPL parameterization, which increases up to 4.2 σ if including SNe data [6]. This result also supported by the Dark Energy Survey BAO and SNe combined analysis [8]. It is worth pointing out that some researches also prefer a DDE without DESI data set [8-11]. Other recent reports, see for example [12-18], also suggest Without making assumptions about a specific DE model, a parameterized Hubble function, or a parameterized EoS for DE, a model-independent method was proposed to analyze H(z) parameter data by using the Lagrange mean value theorem, suggesting possible evidences for physics beyond ΛCDM [10, 11]. This method was generalized to analyze DESI DR2 data, presenting possible evidences that the EoS of DE may be less than -1 during $0.922 < z < 0.955$ and the universe may experience an accelerated expansion during $0.51 < z < 0.955$ [19]. Although these results are attractive, the confidence level is not yet high. Whether dark energy is dynamic or not, and whether its EoS is larger than -1, equal to -1, or less than -1, remains an unresolved and important question.

Here we obtain 5 new data from DESI 2024 BAO measurements and use the modelindependent method proposed in [10, 11, 19] to analyse these data. The results suggest that

the EoS of DE is less than -1 with confidence level exceeding 3.85 σ at z31 (0.51, 0.706).

The paper is structured as follows. In Sec. II, we will present 5 new data obtained from DESI 2024 BAO measurements and the method needed to analyze these data. In Sec. III, we will provide the data and the results obtained from the analysis. In Sec. IV, we will give some conclusions.

METHODOLOGY AND DATA

In this Section, we obtain 5 new data from DESI 2024 BAO measurements by using the rules for propagation of errors and briefly introduce the model-independent method needed

in data analysis.

New data

Constraining the expansion history of the universe during $0.1 < z < 4.2$, BAOs from galaxy surveys can be used to probe the matter dominated era and the recent era of cosmic acceleration. DESI data is the most precise BAO measurements to date, incorporating observations of millions of quasars and galaxies. The unprecedented dataset from DESI enables the construction of detailed 3D maps of the cosmic web, facilitating the precise measurements of the expansion history of the universe [4, 6] and provides robust limitations on the EoS of DE [20, 21].

The DESI data were expressed as the Hubble distance DH /rd , the angle-averaged distance DV /rd , and the transverse comoving distance DM /rd , regularized to the comoving sound horizon at the drag era rd . DESI DR2 also provided 8 data for the ratio of the transverse comoving distance to the Hubble distance, denoted as F DM /DH [6], but the DESI 2024 measurements did not. If rewriting the ratio as F = [DM /rd] / [DH /rd], we can obtain 5 new F data by using the basic rules for propagation of errors from the DESI 2024 BAO measurements, see the Table I. These data are consistent with the 8 F data obtained from DESI 2025 measurements [6] and will contribute to future research on DE.

index z

0.510 0.649 $\pm$ 0.022

0.706 0.839 $\pm$ 0.030

0.930 1.214 $\pm$ 0.028

1.317 2.011 $\pm$ 0.079

2.330 4.661 $\pm$ 0.144

TABLE I: 5 New F data obtained from DESI 2024 BAO measurements.

Methodology

According to the Planck 2018 results: ΩK0 = 0.001 $\pm$ 0.002 [22], we consider a spatially flat universe described by the Friedmann-Robertson-Walker-Lemaître (FRWL) metric ds2 = −dt2 + a2 (t) dr2 + r2 (d$ $2 + sin2 θd$ 2), $where a(t) is the scale factor. The Friedmann equations take the form($ + 3p) ,

where the unit c = 1 is used and the dot denotes the derivative with respect to the t.

The total energy density ρ and the corresponding pressure p contain contributions coming from the nonrelativistic matter, the radiation, and other components. The deceleration parameter, usually used to determine whether the expansion of the universe is speeded up, is defined as q = − 2,

= −1 + (1 + z)

which can be rewritten as q = −1 + (1 + z)

where E(z) = H(z)/H0 . In data fitting, this expression is useful. The total EoS, wt = pt /ρt , can be written in terms of the deceleration parameter as wt = − + q.

In a spatially flat universe, the Hubble distance DH and the transverse comoving distance DM takes the form, respectively, as

DM = (1 + z)DA =

dz 0 , H(z)

where

dz 0 . H(z 0)

In this case, the parameter F is given by F = E(z)

implying 1 dE(z) E(z) dz

Then the deceleration parameter can be rewritten as 1 + z dF q = −1 +

In [19], the mode-independent method introduced in [10, 11] was generalized to analyze DESI DR2 data. Here we directly quote relevant formulas. For any redshift interval with zj < zij < zi , the derivative of F 0 (zij) can be approximated as F 0 (zij)

Fo (zi) − Fo (zj) zi − zj

at 1 σF0 confidence level, where Fo (zi) is the datum with 1 σF (zi) confidence level obtained from observations at redshift zi , and

σF0 =

σF2 i + σF2 j zi − zj

Using Eq. (13), the deceleration parameter in Eq. (12) can be approximated as (2 + zi + zj) Fo (zi) − Fo (zj) q(zij) −1 + Fo (zi) + Fo (zj) zi − zj

with 1 σq confidence level, where σq reads

2 + zi + zj (zi − zj) (Foi + Foj)2

[−2Foi + (zi − zj)]2 σF2 j + [2Foj + (zi − zj)]2 σF2 i .

In Eq. (15), the mid-value approximate method has been adopted [10]: zij (zi + zj)/2 and F (zij) [F (zi) + F (zj)]/2 [Fo (zi) + Fo (zj)]/2.

As Eqs. (15), (16), and therefore (6) indicate, the redshift interval zi −zj and observational systematics in σFi and will affect the reliability of our results. The smaller zi − zj or the larger σFi , the greater σq will be.

APPLICATIONS

Obviously if zi −zj 1, the error σq would be amplified when we use Eqs. (15), (16), and (6) to analyze the obtained F data here in Table I. In order to make the results credible, we take the following limitations during the analysis process: 0.1 . zi − zj . 0.5. The obtained data for q and wt parameters are presented in Table II with 1 σ confidence level. From these data, the following conclusions can be drawn: (a) The universe may undergo an accelerated expansion phase in the redshift range 0.51 < z < 1.317. For instance, the acceleration is suggested with a confidence level exceeding 2.6 σ at redshifts z21 (0.51, 0.706); with 2.4 σ confidence level at redshift z31 (0.51, 0.93); and with more than 1.7 σ confidence level at redshift z42 (0.706, 1.317). (b) The universe may experience a decelerated phase with a confidence level exceeding 1.5 σ at redshifts z43 (0.93, 1.317). (c) The dark energy behaves like phantom with wx $\leq$ wt < -1 with a confidence level exceeding 3.85 σ at redshift z21 (0.51, 0.706). (d) wx $\leq$ wt $< -1/3$ with a confidence level more than 5 σ at redshift z31 (0.51, 0.93), meaning that the expansion of the universe was accelerated with a confidence level more than 5 σ during this period.

Based on the spatially-flat ΛCDM, the phase transition from deceleration to acceleration of the universe occurred at the redshift z 0.632 from the Planck 2018 results [22], which is consistent with the result (b) and (d) here, however, it is not consistent the accelerated expansion of the universe at redshift z42 . The result (c) may imply possible evidence for physics beyond ΛCDM.

index

z21 (0.51, 0.706) -1.07 ± 0.41 -1.04 ± 0.27 z31 (0.51, 0.93)

-0.36 ± 0.15 -0.58 ± 0.10

z42 (0.706, 1.317) -0.30 ± 0.17 -0.14 ± 0.11 z43 (0.93, 1.317) 0.40 ± 0.26
TABLE II: q and wt obtained from DESI' s 2024 BAO measurement.

CONCLUSIONS AND DISCUSSIONS

We obtained 5 new F data by using the rules for propagation of errors to the DESI

2024 BAO measurements. We then adopted a model-independent method introduced in [19] which was generalized from the scheme proposed in [10, 11] to analyze these data, and come to the following conclusions: (a) During the period $0.51 < z < 0.93$, the universe may have an accelerated phase with a confidence level exceeding 5 σ; (b) During the period $0.93 < z < 1.317$, the universe may have a decelerated phase with a confidence level more than 1.5 σ; (c) During the period $0.51 < z < 0.706$, The EoS of DE may be less than -1 with a confidence level more than 3.85 σ.

The results we obtained depend on the DESI 2024 BAO measurements and imply possible evidences beyond ΛCDM. The F (z), q(z), and wt data obtained here can be used to test cosmological models. In future studies, more and more accurately observational data are needed to validate our results.

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[1] S. M. Carroll, "The Cosmological constant," Living Rev.Rel., vol. 4, p. 1, 2001.

[2] R.-J. Yang and S. N. Zhang, "The age problem in ΛCDM model," Mon.Not.Roy.Astron.Soc., vol. 407, pp. 1835–1841, 2010. [3] A. G. Riess, S. Casertano, W. Yuan, L. M. Macri, and D. Scolnic, "Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant and Stronger Evidence for Physics beyond ΛCDM," Astrophys. J., vol. 876, no. 1, p. 85, 2019. [4] A. G. Adame et al., "DESI 2024 VI: cosmological constraints from the measurements of baryon acoustic oscillations," JCAP, vol. 02, p. 021, 2025. [5] A. G. Adame et al., "DESI 2024 VII: cosmological constraints from the full-shape modeling of clustering measurements," JCAP, vol. 07, p. 028, 2025.

[6] M. Abdul Karim et al., "DESI DR2 results. II. Measurements of baryon acoustic oscillations and cosmological constraints," Phys. Rev. D, vol. 112, no. 8, p. 083515, 2025. [7] F. J. Qu et al., "The Atacama Cosmology Telescope: A Measurement of the DR6 CMB Lensing Power Spectrum and Its Implications for Structure Growth," Astrophys. J., vol. 962, no. 2, p. 112, 2024. [8] T. M. C. Abbott et al., "Dark Energy Survey: implications for cosmological expansion models from the final DES Baryon Acoustic Oscillation and Supernova data," 3 2025. [9] T. M. C. Abbott et al., "The Dark Energy Survey: Cosmology Results with 1500 New Highredshift Type Ia Supernovae Using the Full 5 yr Data Set," Astrophys. J. Lett., vol. 973, no. 1, p. L14, 2024. [10] R.-J. Yang, "Possible evidences from H(z) parameter data for physics beyond ΛCDM," New Astron., vol. 108, p. 102180, 2024. [11] R.-J. Yang, "Results from Hubble Parameter Data: Oscillating Dark Energy?," Res. Astron.

Astrophys., vol. 26, no. 1, p. 015003, 2026. [12] G. Gu et al., "Dynamical Dark Energy in light of the DESI DR2 Baryonic Acoustic Oscillations Measurements," 4 2025. [13] E. Chaussidon et al., "Early time solution as an alternative to the late time evolving dark energy with DESI DR2 BAO,"3 2025. [14] E. M. Teixeira, W. Giarè, N. B. Hogg, T. Montandon, A. Poudou, and V. Poulin, "Implications of distance duality violation for the H0 tension and evolving dark energy," 4 2025. [15] C. Garcia-Quintero et al., "Cosmological implications of DESI DR2 BAO measurements in light of the latest ACT DR6 CMB data," 4 2025.

[16] M. Scherer, M. A. Sabogal, R. C. Nunes, and A. De Felice, "Challenging ΛCDM: 5σ Evidence for a Dynamical Dark Energy Late-Time Transition," 4 2025. [17] E. Specogna, S. A. Adil, E. Ozulker, E. Di Valentino, R. C. Nunes, O. Akarsu, and A. A. Sen, "Updated Constraints on Omnipotent Dark Energy: A Comprehensive Analysis with CMB and BAO Data,"4 2025. [18] O. Luongo and M. Muccino, "Model-independent cosmographic constraints from DESI 2024," Astron. Astrophys., vol. 690, p. A40, 2024. [19] R.-J. Yang, "Possible evidences for physics beyond ΛCDM from DESI DR2 data," Mod. Phys.

Lett. A, vol. 41, no. 10, p. 2650043, 2026.

[20] K. Lodha et al., "Extended Dark Energy analysis using DESI DR2 BAO

measurements," 3 [21] R. Calderon et al., "DESI 2024: Reconstructing Dark Energy using Crossing Statistics with DESI DR1 BAO data," 5 2024. [22] N. Aghanim et al., "Planck 2018 results. VI. Cosmological parameters," Astron. Astrophys., vol. 641, p. A6, 2020. [Erratum: Astron.Astrophys. 652, C4 (2021)].

Note: Figure translations are in progress. See original paper for figures.