Questioning Cosmic Acceleration with DESI: The Big Stall of the Universe

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One of the most important discoveries in modern cosmology is cosmic acceleration. However, we find that today's universe could decelerate in the statistically preferred Chevallier-Polarski-Linder (CPL) scenario over the ΛCDM model by cosmic microwave background, type Ia supernova and DESI's new measurements of baryon acoustic oscillations. Using various datasets, at a beyond $5\,\sigma$ confidence level, we demonstrate that the universe experiences a triple deceleration during its evolution and finally reaches the state of the "Big Stall", which predicts that: (i) the universe suddenly comes to a halt in the distant future; (ii) its eventual destiny is dominated by dark matter rather than dark energy ; (iii) it ultimately retains an extremely small fraction of dark energy but exerts an extremely large pressure. Our findings profoundly challenge the established understanding of cosmic acceleration and enrich our comprehension of cosmic evolution.

Introduction. The discovery of cosmic acceleration stands as one of the most profound revelations in modern cosmology, fundamentally altering our understanding of the universe's evolution and destiny. This phenomenon, which depicts the observed increase in the rate of the universe's expansion, has captivated scientists since its unexpected revelation. The implications of cosmic acceleration are vast, touching upon the very nature of space, time, and the fundamental forces that govern the cosmos.

Historically, the prevailing cosmological model suggested that the universe's expansion, initiated by the Big Bang, would gradually decelerate over time due to the gravitational attraction of matter. This view was grounded in Einstein's theory of general relativity and supported by observations of the early cosmic microwave background (CMB) radiation and the large-scale structure of the universe [1–4]. However, precise measurements of distant Type Ia supernovae (SN) challenged this perspective in the late 1990s. Two independent teams, the High-z Supernova Search Team [5] and the Supernova Cosmology Project [6], revealed that these stellar explosions appeared fainter than expected. This inconsistency implied that cosmic expansion was not slowing down but rather accelerating.

The concept of cosmic acceleration introduced a new component into the cosmological framework: dark energy (DE). This enigmatic force, which permeates the fabric of space itself, is believed to drive the accelerated expansion of the universe. Nowadays, the standard cosmological model is the so-called ΛCDM, where DE is usually represented by the cosmological constant (Λ). It also includes cold dark matter (CDM) and ordinary baryonic matter [7–9]. While the ΛCDM scenario has been remarkably successful in explaining a wide range of cosmological observations, the nature of DE remains one of the most profound mysteries in contemporary physics [10–13].

Understanding cosmic acceleration is not merely an academic pursuit; it is essential for addressing fundamental questions about the universe's ultimate fate. If the acceleration continues unabated, the universe will expand indefinitely, leading to a cold and desolate future known as the "heat death" of the universe [14, 15]. In this scenario, the universe becomes increasingly empty as galaxies move farther apart, stars burn out, and the cosmos approaches a state of maximum entropy. This fate implies a universe devoid of usable energy, where no further work can be done, and all physical processes eventually cease.

Alternatively, if the nature of DE evolves over time, the universe's fate could be dramatically different. One possibility is the "Big Rip", where the accelerating expansion becomes so rapid that it overcomes the gravitational, electromagnetic, and nuclear forces holding matter together [16]. In this scenario, galaxies, stars, and even atoms are torn apart, leading to a catastrophic end of the universe. Another intriguing possibility is a cyclical model of the universe, where periods of expansion and contraction repeat indefinitely [17, 18]. In such models, the universe undergoes cycles of birth, expansion, contraction, and rebirth, potentially driven by the dynamics of DE or modifications to general relativity.

Furthermore, some theories propose that the accelerated expansion might slow down or even reverse in the distant future, leading to a "Big Crunch" where the universe collapses back into a singularity [19]. Other speculative scenarios include the "Big Freeze", similar to the heat death but emphasizing the extreme cold and emptiness of the future universe, and the "Vacuum Decay", where a phase transition in the vacuum energy leads to a sudden and dramatic change in the properties of the universe [20].

During the past two decades, the CMB [21–25], baryon acoustic oscillations (BAO) [26–31], weak gravitational lensing [32, 33, 35, 59], galaxy clustering [36, 37], cluster counts [38] and SN observations [5, 6] have further deepened our understanding of cosmic acceleration and confirmed the validity of ΛCDM. However, it confronts at least two challenges, i.e., the cosmological constant conundrum [9–12] and the coincidence problem [39], while suffering from the emergent cosmic tensions of the Hubble constant (H_0) and the matter fluctuation amplitude (S_8) [40–44]. Logically, these advancements compel theorists to study new physics beyond the ΛCDM model in order to resolve these issues (see [43, 44] for reviews).

Recently, the new BAO measurements from the DESI data release two (DR2) [45–49] inspired the explorations of new physics once again, especially, dynamical dark energy (DDE) [50]. Through the combinations of CMB, BAO and SN data, the DESI collaboration reported substantial evidences of DDE. However, in [51], we question the validity of such combinations, because there exist clear tensions among the datasets. Currently, a reliable approach is constraining the evolution of DE with each independent dataset and observe if there are statistical evidences of DDE. Interestingly, we find strong preferences of DDE over ΛCDM for each dataset used. This raises an even more interesting question: Whether cosmic acceleration still holds in such a preferred DDE universe? Employing various datasets, we find that current individual datasets cannot determine whether the present-day universe is accelerating or not.

Model. In the framework of general relativity [52], considering a homogeneous and isotropic universe, the Friedmann equations read as $H^2 = (8\pi G\rho)/3$ and $\ddot{a}/a = -4\pi G(\rho+3p)/3$, where H is the cosmic expansion rate at a scale factor a and ρ and p are the mean energy density and pressure of different species including baryons, dark matter (DM) and DE in the late universe. Combining two Friedmann equations, the normalized Hubble parameter $E(z) \equiv H(z)/H_0$ for a flat CPL universe [53, 54] is shown as

$$E(a) = \left[\Omega_m a^{-3} + (1-\Omega_m)a^{-3(1+\omega_0+\omega_a)}\mathrm{e}^{3\omega_a(a-1)}\right]^{\frac{1}{2}}, \quad (1)$$

where Ω_m is the matter fraction. It reduces to ΛCDM when $\omega_0 = -1$ and $\omega_a = 0$. In terms of the deceleration parameter $q \equiv -\ddot{a}/(aH^2)$, cosmic acceleration requires $\omega_0 < 1/[3(\Omega_m - 1)]$ easily derived from the violation of strong energy condition $\rho + 3p \geqslant 0$, while a super acceleration requires $\omega_0 < 1/(\Omega_m - 1)$ corresponding to the violation of null energy condition $\rho + p \geqslant 0$.

Data and methods. We take 13 BAO measurements from DESI DR2 including the BGS, LRG1, LRG2, LRG3+ELG1, ELG2, QSO and Lyα samples at effective redshifts $z_{\rm eff}$ = 0.295, 0.51, 0.706, 0.934, 1.321, 1.484 and 2.33, respectively [45]. We use three calibrated SN datasets: (i) Pantheon+ including 1701 data points from 18 different surveys in $z \in [0.00122, 2.26137]$ [55]; (ii) Union3 with 22 spline-interpolated data points derived by 2087 SN from 24 different surveys in $z \in [0.05, 2.26]$ [56]; (iii) DESY5 consisting of 1735 effective data points in $z \in [0.025, 1.130]$ [57]. We employ the Planck 2018 high-ℓ `plik` temperature (TT) likelihood at multipoles $30 \leqslant \ell \leqslant 2508$, polarization (EE) and their cross-correlation (TE) data at $30 \leqslant \ell \leqslant 1996$, and the low-$\ell$ TT `Commander` and `SimAll` EE likelihoods at $2 \leqslant \ell \leqslant 29$ [58]. We use conservatively the Planck lensing likelihood [59] from `SMICA` maps at $8 \leqslant \ell \leqslant 400$. We also consider three complementary distance probes: 32 cosmic chronometers (CC) in $z \in [0.07, 1.96]$ [60], 193 gamma ray bursts (GRB) in $z \in [0.03351, 8.1]$ [61] and 156 HII galaxies measurements $z \in [10^{-5}, 2.315]$ [62].

We use the Boltzmann code `CAMB` [63] to compute the background evolution and theoretical power spectra of the universe. To perform the Bayesian analysis, we take the Monte Carlo Markov Chain (MCMC) method to infer the posterior distributions of model parameters using `Cobaya` [64]. We assess the convergence of MCMC chains via the Gelman-Rubin criterion $R-1 \lesssim 0.01$ [65] and analyze them using `Getdist` [66].

We take the uniform priors for free parameters: the baryon fraction $\Omega_b h^2 \in [0.005, 0.1]$, cold DM fraction $\Omega_c h^2 \in [0.001, 0.99]$, acoustic angular scale at the recombination epoch $100\theta_{\rm MC} \in [0.5, 10]$, scalar spectral index $n_s \in [0.8, 1.2]$, amplitude of the primordial scalar power spectrum $\ln(10^{10}A_s) \in [2, 4]$, optical depth $\tau \in [0.01, 0.8]$, present-day DE EoS $\omega_0 \in [-15, 20]$ and amplitude of DE evolution $\omega_a \in [-30, 10]$. To produce a matter-dominated era at high redshifts, we impose the condition $\omega_0 + \omega_a < 0$ in the Bayesian analysis. The reason why we use such wide priors for (ω_0, ω_a) is that a large enough parameter space can completely exhibit the constraining power of DESI BAO data.

Deceleration preferred by data. Although the Planck collaboration has given a $2\,\sigma$ evidence of DDE [21], enough attention is not paid to it due to very loose constraints on (ω_0, ω_a) and the reason that combining previous BAO and SN with CMB data gives no deviation from ΛCDM [21]. In light of the fact that new DESI BAO and SN data independently prefer DDE over ΛCDM [51], the CMB DDE evidence should be given sufficient attention. In Fig.1, we present the parameter spaces of (Ω_m, ω_0) from eight independent datasets including CC, GRB and HII observations, and find that, except for Pantheon+ that give a $1.75\,\sigma$ hint of cosmic acceleration, most of the parameter space from each dataset supports cosmic deceleration (see mean values in Tab.I). Specifically, CMB provides a $1.5\,\sigma$ evidence for deceleration, while DESI, Union3 and DESY5 gives $\sim 1\,\sigma$, $0.43\,\sigma$ and $0.68\,\sigma$ clues, respectively. To demonstrate the stability of our findings, using eight datasets, we show constraints on (ω_0, ω_a) in Fig.1. It is easy to see that all the datasets prefer the DDE region of $\omega_0 > -1$ and $\omega_a < 0$. Note that the CPL model is statistically favored over ΛCDM [51] for these datasets. Therefore, we have verified that the universe could possibly undergo a present-day deceleration in such a preferred DDE universe by data. Interestingly, all the datasets cannot rule out $\omega_0 > 0$, indicating the possibility that the pressure of DE is positive.

Furthermore, employing the error propagation, we derive the redshift evolution of background quantities $\Omega_m(z)$, $q(z)$, $E(z)$ and $\omega(z)$ from different datasets in the CPL model (see Fig.2). Overall, all the datasets support a triple deceleration at the $5\,\sigma$ confidence level, although

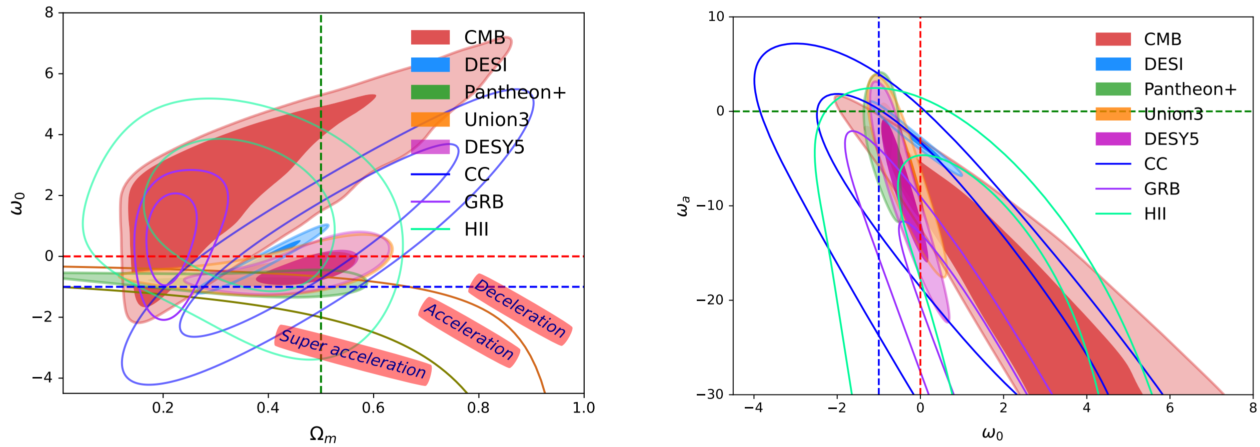

FIG. 1: One-dimensional and two-dimensional posterior distributions of the parameter pairs Ω_m-ω_0 (*left*) and ω_0-ω_a (*right*) from various datasets in the CPL model. The chocolate and olive solid lines are the boundaries of cosmic acceleration and super acceleration. The green dashed lines represents $\Omega_m = 0.5$ (*left*) and $\omega_a = 0$ (*right*). The red and blue dashed lines denote $\omega_0 = 0$ and $\omega_0 = -1$, respectively.

TABLE I: Mean values and $1\,\sigma$ (68.3%) uncertainties of the present-day deceleration parameter q_0 from different datasets in the CPL model.

Data	DESI	CMB	Pantheon+	Union3	DESY5
q_0	0.34 ± 0.41	2.83 ± 1.89	$-0.35^{+0.20}_{-0.21}$	$0.12^{+0.29}_{-0.27}$	0.19 ± 0.28

the redshift ranges of deceleration are slightly different. It is a phenomenon similar to the staged acceleration of a rocket, but in the form of staged deceleration. One phase of deceleration occurred in the past, while the remaining two phases are anticipated to occur in the future. Unfortunately, we cannot determine if today's universe is accelerating with a high significance.

The Big Stall. The ΛCDM model suggests a future where the universe becomes increasingly cold, dark, and empty, with the accelerating expansion driven by DE leading to the ultimate isolation and decay of all structures. However, this is not the case in the CPL model. In Fig.2, we find that all five datasets do not exclude the possibility of present-day matter domination, although DESI DR2 gives a $2.35\,\sigma$ evidence of $\Omega_m < 0.5$. Based on five individual datasets, we confirm the following cosmic expansion history: After a long-term deceleration sourcing from the matter domination, DE starts to become comparable in magnitude to matter and mitigates the rate of deceleration of the universe. However, we cannot ensure whether the universe is accelerating now. Then, the universe will experience the second deceleration when the DE fraction significantly decreases and the universe becomes matter-dominated in the future. As the deceleration of the universe continues decreasing, it will enter the second phase where it is uncertain whether acceleration will resume. Subsequently, when the matter fraction is large enough, the universe will experience continuous deceleration until its acceleration ultimately reaches zero at the end of its existence. Interestingly, throughout this process, the rate of cosmic expansion continuously decreases and also reaches zero at the end of the universe. Conversely, the DE EoS continue increasing and finally become a positive infinity. This indicates that the ultimate fate of the universe is completely stationary with $q(z \to -1) \to 0$ and $E(z \to -1) \to 0$ and matter-dominated. In the meanwhile, the universe will end up with an extremely small DE fraction but an extremely large DE pressure. We call this fate as the "Big Stall". Using the information of the baryon fraction from CMB [21] or BBN [67], the universe is DM-dominated at its end. Note that all the datasets roughly reveal that DE exhibits a phantom-crossing behavior at $2\,\sigma$ level, i.e., $\omega_0 < -1$ in the past and $\omega_0 > -1$ (and $\omega_0 > 0$) in the future.

Concluding remarks. Currently, we cannot determine whether the universe is accelerating and even CMB, DESI DR2, Union3 and DESY5 data slightly prefer cosmic deceleration. This is different from the claim made by two SN teams who confirm cosmic acceleration under Λ. Because all the individual datasets favor the CPL DDE region of $\omega_0 > -1$ and $\omega_a < 0$ and prefer the CPL

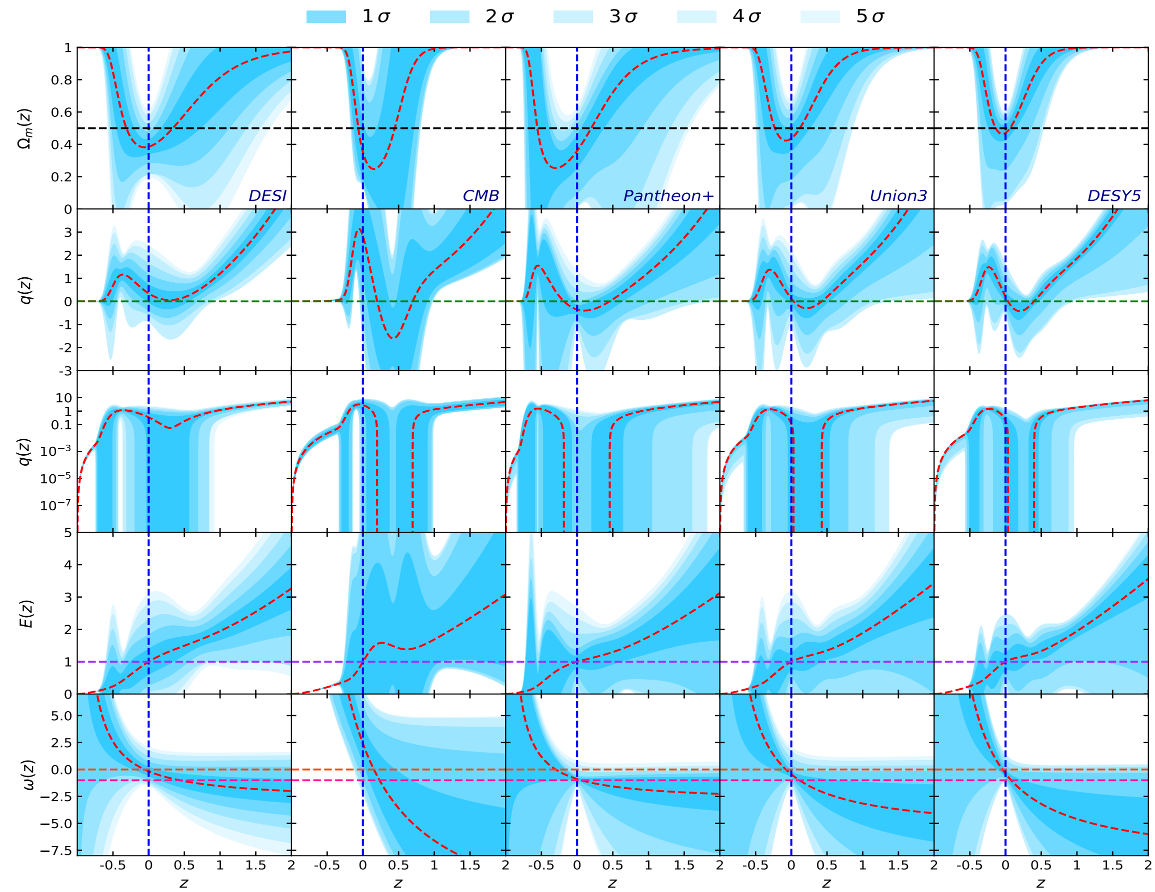

FIG. 2: The $1\,\sigma-5\,\sigma$ regions of background quantities $\Omega_m(z)$, $q(z)$, $E(z)$ and $\omega(z)$ from five individual datasets in the CPL model. As a comparison, we plot $q(z)$ on a logarithmic scale in the third row. The dashed lines denote the mean values of each quantity (red), $z=0$ (blue), $\Omega_m=0.5$ (black), $q=0$ (green), $E=1$ (purple), $\omega_0=0$ (orange) and $\omega_0=-1$ (pink), respectively.

scenario over ΛCDM by a statistical comparison [51], our findings are logically reasonable. So far, there is no any independent dataset that can demonstrate the existence of today's cosmic acceleration in such a preferred universe. Based on this concern, the important contribution from two SN teams should be discovering the existence of dark energy not cosmic acceleration [5, 6].

The combinations of CMB, DESI and SN data give a similar fate of the universe to individual datasets. The main difference is that they strongly support today's cosmic acceleration or DE domination. However, their results are problematic [45, 48], since they suffer from tensions among the datasets. For completeness, we show their background quantities in the supplementary material.

In the CPL model, current observations give a beyond $5\,\sigma$ evidence of the Big Stall with a triple deceleration for the fate of the universe. Completely different from the Big Freeze and the Big Rip, the Big Stall predicts the following novel properties about the fate of the universe: (i) continuously decelerate; (ii) suddenly halt at a distant future; (iii) DM-dominated; (iv) extremely small DE fraction with extremely large pressure and EoS; (v) stars and galaxies could still be active; (vi) galaxies are not isolated; (vii) no black hole era from the Big Freeze; (viii) it will not reaches a state of maximum entropy.

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Supplementary Material for "Questioning Cosmic Acceleration with DESI: The Big Stall of the Universe"

In this supplementary material, we exhibit the redshift evolution of background quantities $\Omega_m(z)$, $q(z)$, $E(z)$ and $\omega(z)$ from four data combinations including CMB+DESI, CMB+DESI+Pantheon+, CMB+DESI+Union3 and CMB+DESI+DESY5 in the CPL model (see Fig.1).

Overall, these combinations provide tighter constraints on each background quantity due to the degeneracy breaking. All the combinations support today's universe is accelerating and dominated by dark energy, while they give stronger evidences of $\omega_0 > -1$ (and $\omega_0 > 0$) in the distant future. Very interestingly, same as individual datasets, all these combinations reveal, a beyond $5\,\sigma$ confidence level, that the universe experiences a triple deceleration during its evolution and finally reaches the state of the "Big Stall". Therefore, the beyond $5\,\sigma$ signal of the universe with a triple deceleration and the Big Stall does not depend on which datasets are used.

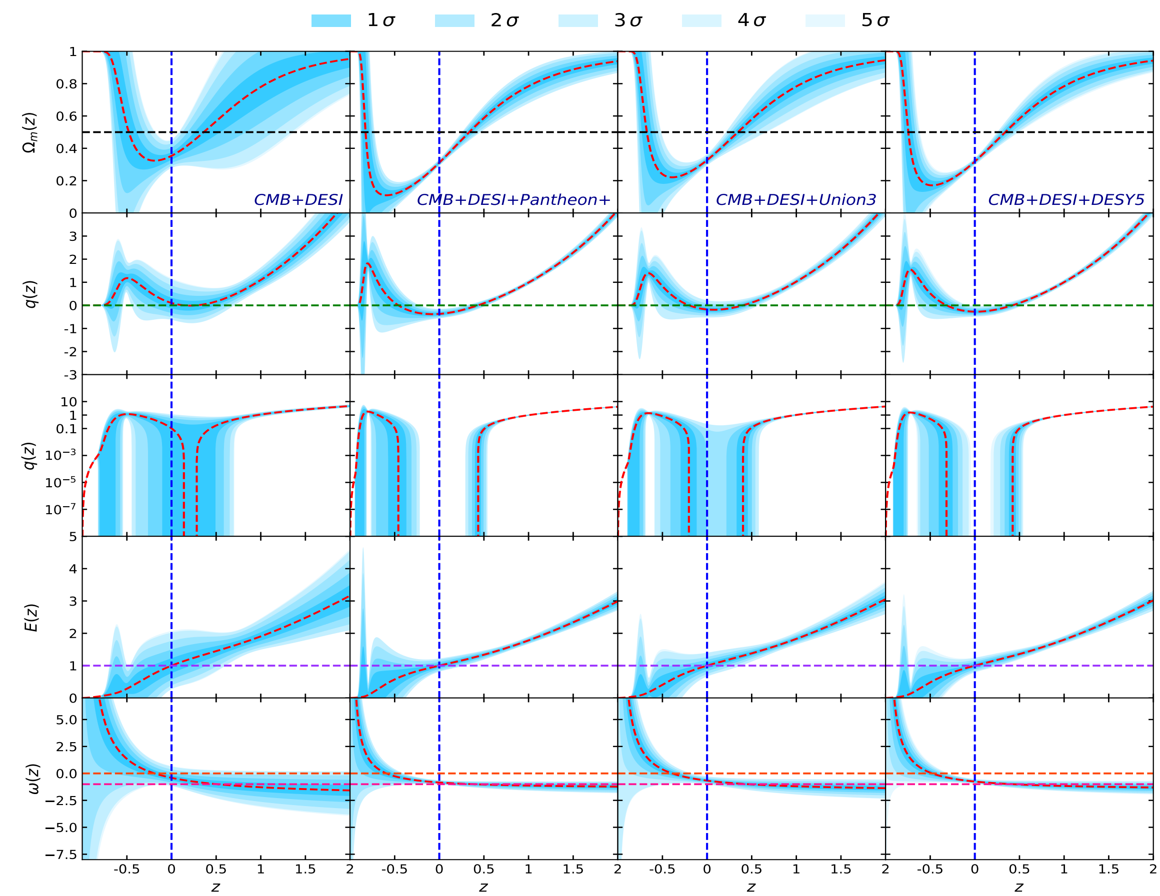

FIG. 1: The $1\,\sigma - 5\,\sigma$ regions of background quantities $\Omega_m(z)$, $q(z)$, $E(z)$ and $\omega(z)$ from different data combinations in the CPL model. As a comparison, we plot $q(z)$ on a logarithmic scale in the third row. The dashed lines denote the mean values of each quantity (red), $z = 0$ (blue), $\Omega_m = 0.5$ (black), $q = 0$ (green), $E = 1$ (purple), $\omega_0 = 0$ (orange) and $\omega_0 = -1$ (pink), respectively.