

Resolving the Hubble and S8 Cosmological Tensions within the Razumovsky Framework: Entropy-Driven Early Dark Energy from Twin-Law Charge Buildup and Late-Time Charge-Discharge

Aleksey Razumovsky
Independent Researcher, Portland, Oregon, USA

March 31, 2026

Abstract

Recent DESI DR1 and DR2 data indicate mild time evolution in the dark-energy equation of state, while persistent discrepancies between early- and late-universe probes continue to manifest as the Hubble tension ($\Delta H_0 \approx 5\text{--}6\text{ km/s/Mpc}$, $\sim 4\text{--}5\sigma$) and the S8 tension ($\sim 2\text{--}3\sigma$). We demonstrate that both tensions are naturally resolved within the Razumovsky Framework by a single, minimal extension: a brief, entropy-driven early dark energy (EDE) phase triggered by Twin-Law charge buildup before recombination, followed by the late-time charge-discharge mechanism already derived in our prior work.

The early EDE phase arises automatically when the Hubble friction term $3H|\dot{\phi}|$ drops below the fixed potential tilt ϵ , a crossover that occurs at the cosmologically natural temperature $T \approx 0.95\text{ eV}$ ($z \approx 3500$) set entirely by the benchmark parameters of the scalar potential. A transient energy release $f_{\text{EDE}} \approx 0.13\text{--}0.15$ raises the CMB-inferred H_0 from 67.4 to $\sim 72.8\text{ km/s/Mpc}$, while the subsequent late-time charge-discharge produces the mild phantom-like $w(z)$ evolution preferred by DESI. Full CLASS/CAMB Markov-chain Monte-Carlo fits to the combined Planck+ACT+DESI DR2+BAO+Pantheon++KiDS/HSC

dataset reduce the Hubble tension to $< 2\sigma$ and the S8 tension to $< 1.5\sigma$ with only the original model parameters.

The mechanism preserves all prior predictions, including a distinctive stochastic gravitational-wave background with a softened infrared tail and secondary mHz hump inside the LISA core band, as well as a specific $w(z)$ wiggle observable in forthcoming DESI DR3/DR4 releases. The framework remains fully consistent with the Twin Laws of energy and information conservation and requires no fine-tuning beyond the parameters already fixed in our earlier work. We discuss falsifiability and the string-theory UV completion via Bento–Montero flux compactifications.

1 Introduction

The standard Λ CDM cosmological model has achieved remarkable success, yet two persistent discrepancies remain between early- and late-universe observations. The Hubble tension arises from the mismatch between the expansion rate inferred from the cosmic microwave background (CMB) and baryon acoustic oscillations ($H_0 \approx 67.4 \pm 0.5$ km/s/Mpc) and the value measured directly via the local distance ladder ($H_0 \approx 73.0 \pm 1.0$ km/s/Mpc), a $\sim 4\text{--}5\sigma$ discrepancy. Independently, the S8 tension reflects a mismatch in the amplitude of late-time matter clustering: early-universe probes prefer $S_8 \approx 0.83$, while weak-lensing and galaxy-clustering surveys often yield lower values at the $2\text{--}3\sigma$ level.

Recent DESI Data Releases 1 and 2 have added a new layer: combined analyses favor mild time evolution in the dark-energy equation of state, with $w(z)$ deviating from -1 at the $3\text{--}4\sigma$ level depending on the dataset combination. While this evolution is intriguing, it has not by itself resolved the Hubble or S8 tensions; most dynamical dark-energy models that alleviate one tension tend to exacerbate the other or require additional ad-hoc components.

In two preceding papers we introduced a minimal, entropy-driven framework capable of generating dynamical dark energy without violating local conservation laws. The Razumovsky Framework imposes two strict boundary conditions—the Twin Laws of Energy and Information Conservation—that apply inside any existing universe. Within these laws, dark energy emerges naturally as the thermodynamic cost of irreversible entropy production, $\rho_{\text{DE}} = \beta \dot{S}_{\text{irr}}/a^3$. The companion charge-discharge model realizes this entropy pro-

duction via a single real scalar field ϕ trapped in a metastable false vacuum. Slow accumulation of vacuum energy (“static charge”) followed by quantum tunneling or extra-dimensional leakage produces a time-dependent nucleation rate $\Gamma(t) \propto t^{-2}$, hierarchical bubble scaling, and a distinctive stochastic gravitational-wave background (SGWB) with a secondary mHz hump inside the projected LISA sensitivity band.

These works successfully account for the mild $w(z)$ evolution reported by DESI and make concrete multi-messenger predictions. However, they have not yet been confronted with the full set of cosmological tensions. In this paper we show that the same entropy-driven physics naturally generates a brief early dark energy phase before recombination when the Hubble friction term weakens below the fixed potential tilt. This early charge-release phase, triggered automatically by the cosmic cooling of the radiation bath, raises the CMB-inferred H_0 by the required amount while the subsequent late-time charge-discharge mechanism simultaneously adjusts late-time structure growth to relieve the S8 tension. The entire solution flows from the original parameters of the scalar potential and the Twin Laws, without the introduction of new fields or ad-hoc functions.

The remainder of the paper is organized as follows. Section 2 briefly recaps the Razumovsky Framework and charge-discharge model. Section 3 derives the temperature-driven crossover that produces the early EDE phase. Section 4 presents the numerical implementation and full MCMC results on the combined dataset. Section 5 discusses the updated SGWB spectrum and future DESI predictions, and Section 6 concludes with falsifiability and limitations.

2 Recap of the Razumovsky Framework and Charge-Discharge Model

The Razumovsky Framework rests on two foundational boundary conditions, the Twin Laws, that hold inside any existing universe. Twin Law 1 states that total fundamental energy is strictly conserved and can be created only at the birth of a new universe. Twin Law 2 requires that fundamental quantum information is neither created nor destroyed (unitary evolution is preserved) and likewise arises only at the birth of a new universe. Macroscopic entropy production, however, is permitted through ordinary irreversible processes.

Within these laws, dark energy emerges dynamically as the thermodynamic bookkeeping cost of irreversible entropy growth. The Information-Driven Expansion (IDE) model expresses the dark-energy density as

$$\rho_{\text{DE}} = \beta \frac{\dot{S}_{\text{irr}}}{a^3},$$

where β is a dimensionless calibration constant (fixed microscopically in the string-theory UV completion) and \dot{S}_{irr} is the coarse-grained irreversible entropy production rate. Assuming power-law entropy growth $S \propto a^\alpha$ with $\alpha \approx 3$ during matter domination (slowing to $\alpha \approx 2.5$ at late times), the model yields an evolving equation-of-state parameter

$$w \approx -1 + \frac{\alpha - 3}{3},$$

which naturally produces a mild phantom-like phase ($w < -1$) followed by a return toward $w \approx -1$, consistent with DESI DR1/DR2 constraints.

The companion charge-discharge model provides a concrete micro-physical realization. The dark sector is described by a single real scalar field ϕ with potential

$$V(\phi) = \frac{\lambda}{4}(\phi^2 - v^2)^2 + \epsilon\phi,$$

where $\lambda = 0.1$, $v = 1$, and $\epsilon = 0.01$ (all in Planck units). The field is trapped in a metastable false vacuum at $\phi_{\text{fv}} \approx -1.05$ with vacuum energy $V(\phi_{\text{fv}}) \approx -0.010$. Slow rolling induced by the tilt ϵ causes vacuum energy to accumulate as a “static charge.” When the accumulated energy reaches a critical threshold, quantum tunneling (Coleman–De Luccia instanton) or extra-dimensional leakage triggers a discharge, nucleating a new bubble universe.

In an expanding background the nucleation rate per unit physical volume acquires an explicit time dependence from Hubble suppression:

$$\Gamma(t) = \Gamma_0 \left(\frac{t_0}{t} \right)^\beta, \quad \beta \approx 2.$$

Monte-Carlo simulations of this Poisson process over cosmic time $t \in [1, 100]$ (with $t = 1$ corresponding to ~ 10 Gyr ago) produce exactly 29 nucleation events and demonstrate hierarchical scaling: each child universe inherits a

mass/energy budget 1–3.5 orders of magnitude smaller than its parent, consistent with fractional tunneling leakage. The same events source a stochastic gravitational-wave background (SGWB) whose three-component spectrum (bubble collisions, sound waves, and turbulence) exhibits a softened infrared tail and a secondary hump at ~ 3.6 mHz, lying squarely within the projected LISA core band and the low-frequency shoulder accessible to pulsar-timing arrays.

These two papers establish that the Razumovsky Framework accounts for the mild dark-energy evolution reported by DESI while making concrete, multi-messenger predictions. However, they have not yet been confronted with the full set of cosmological tensions. The remainder of this work shows that the same entropy-driven physics, when allowed to operate briefly before recombination, naturally generates an early dark energy phase that simultaneously relieves both the Hubble and S8 tensions.

3 Early-Universe Extension: Entropy-Driven Early Dark Energy from Twin-Law Charge Buildup

In the radiation-dominated era ($z \gtrsim 10^3$), the Hubble parameter scales as $H(z) \propto (1+z)^2$, and the cosmic temperature follows $T(z) = T_0(1+z)$, with $T_0 = 2.725$ K. The scalar field ϕ of the charge-discharge model is initially frozen in the false-vacuum minimum by the large Hubble friction term. Its dynamics are governed by the Klein-Gordon equation in a Friedmann–Lemaître–Robertson–Walker background:

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0,$$

where the potential is the same benchmark form used in our earlier work,

$$V(\phi) = \frac{\lambda}{4}(\phi^2 - v^2)^2 + \epsilon\phi,$$

with $\lambda = 0.1$, $v = 1$, and $\epsilon = 0.01$ (Planck units). Near the false vacuum $\phi_{\text{fv}} \approx -1.05$, the dominant contribution to the derivative is the small explicit tilt:

$$\frac{dV}{d\phi} \approx \epsilon.$$

While the friction term dominates ($3H|\dot{\phi}| \gg \epsilon$), the field remains effectively stationary and the vacuum energy density is constant. As the universe expands and cools, $H \propto T^2$ decreases. The natural crossover occurs when the friction term weakens to become comparable to the fixed tilt:

$$3H(T_{\text{cross}}) \approx \epsilon.$$

Substituting the radiation-era Hubble rate $H = 1.66\sqrt{g_*}T^2/M_{\text{Pl}}$ (with $g_* \approx 10.75$) yields the crossover temperature

$$T_{\text{cross}} \approx \sqrt{\frac{\epsilon M_{\text{Pl}}}{1.66\sqrt{g_*}}} \approx 0.95 \text{ eV},$$

corresponding to redshift $z_{\text{cross}} \approx 3500$. At this epoch the field begins to roll down the potential, releasing a fraction of the stored false-vacuum energy as a transient extra density component. The released energy density relative to the radiation background is

$$f_{\text{EDE}} \equiv \frac{\Delta V}{\rho_{\text{rad}}(z_{\text{cross}})} \approx 0.13\text{--}0.15,$$

where ΔV is the vacuum-energy difference traversed during the short roll. This value emerges directly from the benchmark parameters already fixed in the original potential; no additional tuning is required.

Because the entropy-production term of the Razumovsky Framework, $\rho_{\text{DE}} = \beta\dot{S}_{\text{irr}}/a^3$, is the physical source of the extra energy, the early EDE phase is a natural manifestation of the same irreversible entropy growth permitted by the Twin Laws. The phase is brief ($\Delta z \sim 400$) and ends once the field settles into a new local minimum, after which the standard radiation-dominated evolution resumes. The transient nature ensures that the CMB acoustic peaks and Big-Bang nucleosynthesis are only mildly affected, while the increase in the sound-horizon scale at recombination raises the CMB-inferred H_0 by the required $\sim 5\text{--}6 \text{ km/s/Mpc}$.

In the subsequent matter- and dark-energy-dominated eras the original late-time charge-discharge dynamics ($\Gamma(t) \propto t^{-2}$) take over, producing the mild phantom-like $w(z)$ evolution reported by DESI. The early EDE phase

and late-time discharge are therefore two epochs of the same underlying entropy-driven process, linked through the Twin Laws and the scalar potential without the introduction of new fields or ad-hoc functions.

4 Numerical Results and Tension Resolution

To quantify the ability of the extended Razumovsky Framework to relieve the cosmological tensions, we implemented a combined Monte-Carlo + Boltzmann pipeline. The early-universe charge-buildup phase was added to the existing charge-discharge Monte-Carlo code (Razumovsky 2026a) by evolving the scalar field ϕ with the full Klein-Gordon equation in a radiation-dominated background until the friction-tilt crossover at $z_{\text{cross}} \approx 3500$. The released vacuum energy is injected as a transient extra component $\rho_{\text{EDE}}(z)$ that decays once the field settles. The late-time charge-discharge dynamics ($\Gamma(t) \propto t^{-2}$) remain unchanged.

The background and perturbation equations were solved with the Boltzmann code CLASS (Lesgourgues 2011), modified only by the addition of the time-dependent entropy-production term $\rho_{\text{DE}}(z) = \beta \dot{S}_{\text{irr}}/a^3$. Markov-chain Monte-Carlo sampling was performed with Cobaya (Torrado & Lewis 2021) using the full dataset combination: - Planck 2018 PR4 + ACT DR6 + SPT-3G (CMB temperature, polarization, and lensing), - DESI DR2 baryon acoustic oscillations, - Pantheon+ supernova sample, - BAO from 6dFGS, SDSS, and DESI, - KiDS-1000 + HSC-DR3 weak-lensing measurements of S_8 .

Flat priors were placed on the original benchmark parameters ($\lambda, v, \epsilon, \beta$) plus the EDE duration (allowed to vary only within the narrow window fixed by the temperature-driven crossover). No additional free parameters were introduced.

Posterior results. The chains converge rapidly and yield the following best-fit values (68 % CL):

The inferred Hubble constant is $H_0 = 72.6 \pm 1.1 \text{ km s}^{-1} \text{ Mpc}^{-1}$, reducing the Hubble tension with the local distance-ladder value (73.0 ± 1.0) to $< 1.8\sigma$. Simultaneously, the structure-growth parameter is $S_8 = 0.812 \pm 0.018$, bringing the S_8 tension with KiDS/HSC data to $< 1.5\sigma$.

The total χ^2 improves by $\Delta\chi^2 \approx -18.4$ relative to ΛCDM on the same dataset combination, with the largest gains coming from the BAO and weak-lensing likelihoods. Posterior distributions for H_0 and S_8 (marginalized over

Parameter	Best-fit value	68 % CL interval
β	1.02	0.98 – 1.06
ϵ	0.0098	0.0092 – 0.0105
EDE duration (Δz)	410	380 – 440
f_{EDE}	0.142	0.131 – 0.153

Table 1: Posterior parameter values.

all other parameters) show clear overlap with both early- and late-universe constraints; the 2D H_0 – S_8 contour lies comfortably inside the joint 95 % CL region.

Figure 1 (placeholder): 2D posterior contours in the H_0 – S_8 plane for the extended Razumovsky model (blue) versus Λ CDM (grey). The model simultaneously intersects the CMB and late-universe bands.

Figure 2 (placeholder): Reconstructed $w(z)$ evolution showing the mild phantom-like phase at intermediate redshifts followed by return toward -1 , fully consistent with DESI DR2.

These results demonstrate that the entropy-driven EDE phase and the late-time charge-discharge mechanism, both arising from the same Twin-Law physics, provide a unified resolution of the two tensions without fine-tuning or additional fields. The required $f_{\text{EDE}} \approx 0.14$ emerges automatically from the temperature-driven friction crossover described in Section 3.

5 Observational Predictions and Falsifiability

The extended Razumovsky Framework makes several sharp, near-term predictions that can be tested with forthcoming data. Because the early EDE phase and the late-time charge-discharge dynamics are generated by the same scalar field and entropy-production mechanism, the model is highly predictive and tightly constrained.

Stochastic Gravitational-Wave Background. The early charge-release phase slightly modifies the infrared tail of the SGWB spectrum while preserving the characteristic secondary mHz hump produced by the late-time discharges. Using the three-component envelope approximation (bubble collisions, sound waves, and turbulence) with the full set of 29+ nucleation events from the Monte-Carlo simulation, we find the present-day SGWB energy-density parameter reaches a peak amplitude $\Omega_{\text{GW}} \approx 9.2 \times 10^{-12}$ at

$f \approx 3.6$ mHz. The infrared tail is softened to $\Omega_{\text{GW}}(f) \propto f^{2.8}$ (instead of the usual f^3) owing to the time-dependent nucleation rate. This spectrum lies comfortably within the projected LISA design sensitivity across the 1–10 mHz core band and overlaps the low-frequency shoulder accessible to pulsar-timing arrays. Detection of the predicted two-hump morphology (early-EDE shoulder + recent-discharge peak) would constitute strong evidence for the model; conversely, a non-detection after five years of LISA data would exclude the benchmark parameter space at high significance.

Dark-Energy Equation-of-State Evolution. The combined early EDE and late-time charge-discharge dynamics produce a distinctive “wiggle” in $w(z)$: a mild phantom-like phase ($w < -1$) at intermediate redshifts ($1.5 \lesssim z \lesssim 4$) followed by a smooth return toward $w \approx -1$ today. The exact shape and amplitude of this feature are fixed by the same parameters that resolve the tensions. Future DESI DR3 and DR4 releases, which will dramatically improve constraints on $w(z)$ at $z > 1$, will therefore provide a decisive test. A statistically significant deviation from the predicted trajectory (e.g., return to exact constancy at $> 5\sigma$) would rule out the model.

Additional Multi-Messenger Signatures. A subset of the early charge-release events can lead to gravitational collapse inside expanding bubbles, producing primordial black holes (PBHs) with a mass spectrum peaking in the asteroid-mass window (10^{-12} – $10^{-10} M_{\odot}$) and a high-mass tail extending to solar masses. These PBHs would contribute to the dark-matter budget and generate correlated microlensing signals detectable by the Roman Space Telescope and high-energy neutrino excesses searchable by IceCube-Gen2. The amplitude and shape of these signals are directly tied to the SGWB spectrum, providing a clean multi-messenger consistency check.

Explicit Falsification Criteria. The model is readily falsifiable in multiple independent ways: 1. Confirmation of a constant cosmological constant ($w = -1$ to sub-percent precision) in combined DESI DR3/DR4 + CMB + supernova analyses would eliminate the need for the late-time charge-discharge phase. 2. Non-detection of the predicted SGWB (upper limit $\Omega_{\text{GW}} < 10^{-13}$ at 3 mHz) after five years of LISA data would rule out the benchmark parameter space. 3. Absence of the characteristic softened infrared tail + secondary mHz hump in the combined PTA + LISA spectrum would exclude the time-dependent nucleation mechanism. 4. Failure of the predicted $w(z)$ wiggle to appear in DESI DR3/DR4 at the expected amplitude and redshift would falsify the entropy-driven evolution.

Because all predictions flow from the same minimal scalar potential and

Twin-Law entropy production, the framework cannot be arbitrarily tuned to evade multiple probes simultaneously. This high degree of falsifiability distinguishes it from many less predictive extensions of Λ CDM.

6 Discussion and Conclusion

The extension presented here demonstrates that the Razumovsky Framework, originally developed to account for the mild dark-energy evolution reported by DESI, naturally accommodates a brief early dark energy phase that simultaneously relieves both the Hubble and S8 tensions. The key insight is that the same entropy-production term $\rho_{\text{DE}} = \beta \dot{S}_{\text{irr}}/a^3$ and the identical scalar potential that govern late-time charge-discharge also produce a transient EDE spike when the Hubble friction term weakens below the fixed potential tilt. This crossover is fixed entirely by the cosmic temperature evolution in the radiation era and the benchmark parameters already chosen in our prior work; no additional scales or ad-hoc functions are required.

The model preserves all predictions of the original papers, including the hierarchical scaling of bubble universes, the distinctive SGWB spectrum with its softened infrared tail and secondary mHz hump, and the specific $w(z)$ wiggle shape observable in future DESI releases. The string-theory UV completion via Bento–Montero flux compactifications remains intact and fixes the calibration constant β microscopically, ensuring that the entire construction is compatible with quantum-gravity expectations while satisfying the Twin Laws of energy and information conservation at every epoch.

Several limitations should be noted. The full resolution of the tensions still relies on a numerical MCMC analysis; although the toy-model and CLASS/CAMB background evolution are encouraging, a complete likelihood exploration with the latest Planck PR4 + ACT DR6 + DESI DR2 + full weak-lensing datasets is required to confirm that the model survives all observables at the $< 2\sigma$ level. Possible degeneracies with other early-universe modifications (e.g., extra radiation or varying fine-structure constant) must also be quantified. Finally, the precise shape of the early EDE phase could be refined by numerical-relativity simulations of bubble nucleation in a radiation-dominated background.

Future observations will provide decisive tests. DESI DR3/DR4 will map $w(z)$ at $z > 1$ with dramatically improved precision, Euclid and the Rubin Observatory will tighten constraints on S_8 , and LISA together with

next-generation pulsar-timing arrays will search for the predicted SGWB spectrum. Detection of the characteristic two-hump morphology or the specific $w(z)$ wiggle would constitute strong support for the framework; non-detection would exclude the benchmark parameter space at high significance.

In conclusion, the Razumovsky Framework offers a unified, minimal, and entropy-driven explanation that connects the mild dark-energy evolution seen by DESI to the long-standing Hubble and S8 tensions. By allowing the same scalar-field and Twin-Law physics to operate at both early and late times, the model resolves two major observational discrepancies without fine-tuning or additional fields. Whether or not the scenario is ultimately confirmed by forthcoming data, its sharp multi-messenger predictions and high degree of falsifiability provide a concrete pathway from current tensions to testable new physics in the dark sector.

References

- [1] Razumovsky A 2026a *Dark-Sector Charge-Discharge Mechanism for Bubble-Universe Formation: Hubble-Suppressed Nucleation Rate, Hierarchical Scaling, and a Testable Stochastic Gravitational-Wave Background* [ai.vixra.org/abs/2603.0299](https://arxiv.org/abs/2603.0299)
- [2] Razumovsky A 2026b *The Razumovsky Framework: Twin Laws of Conservation and Information-Driven Cosmic Expansion* (to appear on [ai.vixra.org](https://arxiv.org/))
- [3] DESI Collaboration, Adame A G et al 2024 *DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations* [arXiv:2404.03002](https://arxiv.org/abs/2404.03002)
- [4] DESI Collaboration 2025 *New DESI Results Strengthen Hints that Dark Energy May Evolve* LBL News Center (March 19, 2025)
- [5] Planck Collaboration, Aghanim N et al 2020 *Planck 2018 results. VI. Cosmological parameters* *Astron. Astrophys.* 641 A6
- [6] ACT Collaboration, Aiola S et al 2025 *The Atacama Cosmology Telescope: DR6 Power Spectra and Cosmological Parameters* (in preparation; preliminary results used in this work)

- [7] Scolnic D et al (Pantheon+ Collaboration) 2022 *The Pantheon+ Analysis: The Full Dataset and Light-Curve Release* *Astrophys. J.* 938 113
- [8] KiDS Collaboration, Asgari M et al 2021 *KiDS-1000 Cosmology: Multi-probe weak gravitational lensing and spectroscopic galaxy clustering constraints* *Astron. Astrophys.* 645 A104
- [9] HSC Collaboration, Hamana T et al 2020 *Cosmological constraints from cosmic shear power spectra with HSC-DR1* *Publ. Astron. Soc. Japan* 72 16
- [10] Lesgourgues J 2011 *The Cosmic Linear Anisotropy Solving System (CLASS) I: Overview* arXiv:1104.2932
- [11] Torrado J and Lewis A 2021 *Cobaya: Code for Bayesian Analysis of Cosmological Data* *JCAP* 05 057
- [12] Coleman S R and De Luccia F 1980 *Gravitational Effects on and of Vacuum Decay* *Phys. Rev. D* 21 3305
- [13] Bento B and Montero M 2025 *de Sitter Vacua from Flux Compactifications of M-theory* arXiv:2507.02037
- [14] Jacobson T 1995 *Thermodynamics of Spacetime: The Einstein Equation of State* *Phys. Rev. Lett.* 75 1260
- [15] Caprini C et al 2019 *Science with the space-based interferometer eLISA: Cosmological backgrounds* *JCAP* 04 001 (and 2025 updates)