Dark Energy as Geometry: The Selective Transient Field Framework and the T^2 Causal Diamond

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Abstract

We present the dark energy sector of the Selective Transient Field (STF) framework — a unified scalar-field theory in which dark matter and dark energy emerge from the same scalar field, the breathing mode of six compact extra dimensions in a 10D Einstein-Gauss-Bonnet compactification on a Calabi-Yau threefold (CICY #7447) with Z_{10} free quotient structure. The STF scalar has mass $m_s = 3.94 \times 10^{-23}$ eV and coupling $\zeta/\Lambda = 1.35 \times 10^{11}\ \text{m}^2$, both derived from first principles. The dark energy component arises from the residual potential energy $V(\varphi_{min})$ at the stabilized modulus, modulated by the T^2 causal-diamond integral $\alpha(\theta) = \int_0^\theta \cos^2(\theta')d\theta'$. The current epoch is identified with $\theta = \pi/2$ by the geometric condition $|R_0|/c^2 = 4\Lambda_{eff}$ (Paz 2026a, §III.E Prediction 6), which gives $\Omega_m = 4/(3(1+\pi)) \approx 0.322$ — within 1σ of Planck 2018 (0.315 ± 0.007) and consistent with DESI DR1/DR2 (0.295–0.307, model-dependent). The third-order tangency $d\alpha/d\theta|_{\pi/2} = \cos^2(\pi/2) = 0$ forces $\Lambda_{eff} = 0$ at the current epoch, predicting **$w(z=0) = -1$ exactly** (independent of the compactification time-scale $T_{compact}$). At earlier epochs $\theta < \pi/2$ the coupling was accumulating, giving an effective phantom trajectory **$w(z) < -1$ for all $z > 0$** (sign rigorous; magnitude conditional on $T_{compact}$, see Paz 2026c §6.1) without a phantom crossing. The STF is a DHOST Class Ia theory with positive scalar kinetic energy and $c_T = c$ exactly (GW170817-compatible, Paz 2026a §C.6); the apparent phantom behaviour is **effective**, arising from T^2 geometric coupling accumulation, not fundamental ghost behaviour. The same nodal structure that gives $w_0 = -1$ also gives $c_s^2(z=0) = 1$ exactly (Paz 2026c §6.3) — perturbation stability paired with the equation-of-state result. We conduct a systematic comparison with eight competing dark energy frameworks: the cosmological constant Λ, quintessence, k-essence, phantom dark energy, w_0w_aCDM (CPL parameterization), early dark energy, scalar-tensor dark energy (Horndeski/DHOST), and emergent dark energy models. We compile and contextualize recent observational evidence: (i) the 2.8–4.2σ statistical preference for w_0w_aCDM over ΛCDM in DESI DR2 + CMB + SNe combined fits (Adame et al. 2024, Karim et al. 2025), with best-fit indicating evolving dark energy ($w_0 > -1$ today, $w_a < 0$); (ii) the Euclid Quick Data Release Q1 (March 2025) sky coverage of 63 deg^2 as a precursor to its first cosmology release (October 2026); (iii) recent debates about the prior dependence of the DESI w_0w_a result (Cortês & Liddle 2024, 2025); and (iv) alternative interpretations including coupled dark sector models (Roy Choudhury et al. 2025) and evolving dark matter scenarios (Chen & Loeb 2025). The DESI DR2 best-fit trajectory — apparent quintom-B ($w<-1$ in past, crossing to $w>-1$ today) — is **structurally opposite** to the STF prediction (no crossing; monotonic phantom for $z > 0$; $w_0 = -1$ exactly). We treat this as a serious observational tension that the framework must address honestly: if direct measurements confirm the quintom-B sign, the T^2 nodal structure is falsified at $>3\sigma$. The framework's structural prediction is that $w_0 = -1$ lies *exactly on* the cosmological constant, with all evolution into the past. Euclid's first cosmology release (October 2026) will be decisive. We also address theoretical aspects: the GW170817 constraint $c_T = c$ (satisfied structurally by $G_4X = 0$); the no-go theorem for fundamental phantoms (evaded by DHOST Class Ia structure); the relationship to the DESI w_0w_a best-fit (categorically different mechanism — STF's effective phantom is monotonic, DESI's CPL is a parametrization artifact of strongly anticorrelated posteriors). We present six testable predictions, three falsifiability classes (rigorous-structural, conditional-magnitude, derived-extension), and a prediction-dependency map indicating which observables survive if any single component fails. The unified dark sector picture — one scalar field producing both the dark-matter equation of state $\langle w \rangle = 0$ (Paz 2026d) and the dark-energy structural prediction $w(z=0) = -1$ — is structurally over-constrained relative to a fitted dual-component model. Of the framework's testable predictions, the structural prediction $w(z=0) = -1$ *exactly* is the most distinctive: it is independent of T_compact, derives from T^2 differential topology rather than parameter fitting, and is the single most directly testable element of the framework against forthcoming Euclid data.

Keywords: dark energy, equation of state, T^2 causal diamond, third-order tangency, DHOST Class Ia, GW170817, phantom dark energy, scalar field cosmology, DESI w_0w_aCDM, Euclid mission, Calabi-Yau compactification, ghost-free scalar-tensor gravity, effective phantom without ghost, unified dark sector, cosmological constant problem

I. Introduction

The accelerating expansion of the universe, discovered through Type Ia supernova observations (Riess et al. 1998, Perlmutter et al. 1999), has been cosmology's most enduring puzzle for over a quarter century. The simplest description — a cosmological constant Λ — fits the data well but raises three deep theoretical problems.

The cosmological constant problem. Quantum field theory naively predicts a vacuum energy density $\sim10^{122}$ times larger than observed (Weinberg 1989). No accepted derivation of the observed value from microphysics exists. The vast disparity between predicted and observed scales is among the most severe fine-tuning problems in physics.

The coincidence problem. Within ΛCDM, dark matter and dark energy densities differ by orders of magnitude at most cosmic epochs but happen to be comparable now, with $\Omega_m \approx 0.32$ and $\Omega_\Lambda \approx 0.68$. Why this near-equality occurs at the current epoch — rather than billions of years earlier or later — has no explanation in the standard framework.

The dynamical question. Is dark energy a true cosmological constant ($w = -1$ exactly, time-independent), or does it evolve? If it evolves, does it cross the phantom boundary $w = -1$, and if so, in which direction?

The Dark Energy Spectroscopic Instrument (DESI) Year-1 BAO results (Adame et al. 2024) and the Year-2 Data Release (Karim et al. 2025) have transformed the empirical landscape on this question. Combined fits of DESI BAO with cosmic microwave background distance priors and Type Ia supernova compilations (Pantheon+, DES Year-5, Union3) now show a 2.8–4.2σ statistical preference for the w_0w_aCDM parameterization over a constant Λ. The best-fit shows $w_0 > -1$ today (quintessence-like at present) with $w_a < 0$ (phantom in the past), indicating an apparent **quintom-B trajectory** with phantom crossing in the recent past. If confirmed, this would be the most significant empirical development in cosmology since the discovery of acceleration itself.

However, the result is contested. Cortês & Liddle (2024, 2025) demonstrated that the DESI Bayesian preference for w_0w_aCDM is sensitive to the priors imposed on w_0 and w_a — extending the lower bounds beyond −4.6 (for w_0) and −5 (for w_a) reverses the preference toward ΛCDM. Roy Choudhury et al. (2025) showed that updating the CMB likelihood from Planck PR3 to PR4 weakens the dynamical-dark-energy preference. Chen & Loeb (2025) proposed that the DESI signal can be reproduced by an evolving dark matter component rather than evolving dark energy. The empirical case for dynamical dark energy is suggestive but not yet conclusive.

The Euclid space telescope (launched July 2023, beginning its cosmological survey February 2024) will provide the next major step. Its Quick Data Release Q1 (March 2025) covered 63 deg^2 — a precursor to the first cosmology data release in October 2026, which will probe dark energy through a combination of weak gravitational lensing, galaxy clustering, and BAO measurements over much wider sky coverage than DESI.

This paper presents the dark energy sector of the **Selective Transient Field (STF) framework** — a unified scalar-field theory in which dark matter and dark energy emerge from the same scalar field. The STF was developed primarily as a UV-complete model of dark matter, deriving from a 10D Einstein-Gauss-Bonnet compactification on the Calabi-Yau threefold CICY #7447 with Z_{10} free quotient structure (Paz 2026a, hereafter “the First Principles paper”). The dark-matter aspects of the framework are presented in Paz 2026d (“Dark Matter as Geometry: The STF Framework for a Unified Dark Sector”); the present paper is its parallel for the dark-energy sector.

I.A Why a separate dark-energy paper

The unified-dark-sector framing might suggest that dark energy and dark matter should be addressed in a single paper. Three reasons make a separate dark-energy treatment appropriate:

(1) The observational landscapes differ qualitatively. Dark matter is constrained primarily by galactic kinematics, gravitational lensing, structure formation, and direct-detection null results. Dark energy is constrained primarily by Type Ia supernova distances, BAO from spectroscopic galaxy surveys, CMB acoustic peaks, weak lensing tomography, and (forthcoming) redshift-space distortions and 21-cm cosmology. The competing-theory landscapes are also different: ΛCDM, MOND, fuzzy DM, WDM, SIDM, superfluid DM, and emergent gravity for dark matter; cosmological constant, quintessence, k-essence, phantom, w_0w_aCDM, early DE, and scalar-tensor DE for dark energy.

(2) The structural mechanisms differ. The STF dark-matter mechanism rests on the oscillation-averaging of the scalar field at cosmological scales (giving $\langle w\_DM \rangle = 0$) combined with the field’s response to galactic geometry (giving the MOND phenomenology). The STF dark-energy mechanism rests on the residual potential energy at the stabilized modulus combined with the T^2 causal-diamond integral structure (giving the $w(z=0) = -1$ nodal result). These are different microphysical mechanisms within the same framework, deserving separate analysis.

(3) The observational tests are temporally separated. The dark-matter predictions test against existing rotation curves, SPARC catalog, Lyman-α constraints, and dwarf-galaxy kinematics. The dark-energy predictions test against forthcoming Euclid w(z) measurements (October 2026 first cosmology release) and DESI DR3+ analyses. The two test programs run on different timescales and require different observational synthesis.

I.B What this paper contributes

This paper makes three primary contributions to the STF framework’s publication portfolio:

(1) A self-contained dark-energy treatment. Sections II–III present the STF framework’s relevant structure for dark energy (compact summary) followed by the explicit derivation of the w(z) result from T^2 causal-diamond geometry. The full calculation chain is in Paz 2026c (“STF Dark Energy w(z) Derivation V0.2”); this paper presents the result in publication form with observational context.

(2) A systematic comparison with competing dark-energy theories. Section IV compares the STF prediction against eight competing dark-energy frameworks, identifying for each: the underlying mechanism, observational successes, theoretical vulnerabilities, and the specific aspects in which the STF differs. The comparison is honest — the STF is not advertised as superior in every respect, and the empirical case for STF over alternatives is qualified by the open T_compact question and the current observational tensions.

(3) Engagement with the DESI DR2 observational tension. The DESI DR2 result, if confirmed, falsifies the STF dark-energy prediction at $>3\sigma$. Section V addresses this directly: we present the DESI result honestly, discuss the prior-dependence and CMB-likelihood concerns, examine alternative interpretations, and identify the specific Euclid measurements that would be decisive. We do not minimize the tension or massage the prediction to accommodate it. The framework's structural prediction is $w_0 = -1$ exactly; if the empirical case for $w_0 > -1$ strengthens, the framework is in serious trouble. We discuss the falsification scenarios explicitly.

I.C Roadmap

Section II presents the STF framework, focused on the elements relevant for dark energy. Section III develops the STF dark-energy sector: the residual potential, the T^2 causal-diamond structure, the third-order tangency, and the resulting predictions $w(z=0) = -1$ and $c_s^2(z=0) = 1$. Section IV conducts the systematic comparison with eight competing dark-energy theories. Section V compiles recent observational evidence and addresses the DESI DR2 tension. Section VI provides an honest assessment of STF's limitations. Section VII presents testable predictions with falsifiability classes and a prediction-dependency map. Section VIII discusses broader implications and the unified dark sector picture. Section IX concludes.

II. The Selective Transient Field Framework

This section summarizes the STF framework's structure, focusing on the elements relevant for the dark-energy analysis. Comprehensive treatments are in Paz 2026a (the First Principles paper, full mathematical derivation) and Paz 2026d (the Dark Matter paper, applied phenomenology).

II.A The STF Lagrangian

The STF Lagrangian is:

$$ \mathcal{L}_{\rm STF} = -\frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m_s^2\phi^2 + \frac{\zeta}{\Lambda}g(\mathcal{R})\phi(n^\mu\nabla_\mu\mathcal{R}) + \mathcal{L}_{\rm matter\ couplings} $$

where φ is the scalar field, m_s is the field mass, ζ/Λ is the coupling constant, $\mathcal{R}$ is the Weyl/Ricci tidal scalar (regime-dependent — see §II.D), $n^\mu = \nabla^\mu\varphi/\sqrt{2X}$ is the unit vector along the field gradient, and $g(\mathcal{R})$ is a smooth threshold function. The matter couplings include the cross-disformal coupling required for the flyby anomaly and galactic phenomenology (see Paz 2026b).

Field mass. $m_s = 3.94 \times 10^{-23}$ eV, derived from the cosmological threshold condition $\mathcal{D}_{\rm crit} = \mathcal{D}_{\rm GR}$ (Paz 2026a §III.D), which identifies scalar field activation at the orbital separation where binary black hole inspiral becomes cumulative — 730 R_S, corresponding to a period of $T = 3.32$ years via the Peters (1964) inspiral formula. The oscillation frequency is $\omega_s = m_s c^2/\hbar = 5.98 \times 10^{-8}$ rad/s.

Coupling constant. $\zeta/\Lambda = 1.35 \times 10^{11}$ m², derived from 10D Einstein-Gauss-Bonnet compactification on CICY #7447/$\mathbb{Z}_{10}$ (Paz 2026a, Appendices L and O). The independent validation route through the Anderson flyby anomaly (Paz 2026a, Appendix B) matches the empirically measured $K = 2\omega R/c$ coefficient to 99.99% at planetary scales, with the caveat that the Anderson anomaly is itself debated (proposed conventional explanations include thermal radiation pressure and orbit-determination systematics, Anderson et al. 2008). The flyby validation provides a cross-domain check on the coupling but is not central to the dark-energy analysis: the STF dark-energy predictions follow from the cosmological-scale dynamics of φ on FRW backgrounds, independent of the flyby validation.

II.B The 10D compactification and CICY #7447/$\mathbb{Z}_{10}$

The compactification chain proceeds through:

$$ S_{10} = \int d^{10}x\sqrt{|g_{10}|}\left[\frac{1}{2\kappa_{10}^2}R_{10} + \alpha_{\rm GB}\,\mathcal{G}_{10}\right] $$

with the Gauss-Bonnet term $\mathcal{G}_{10} = R^2 - 4R_{\mu\nu} R^{\mu\nu} + R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$. The breathing-mode reduction:

$$ g_{10} = e^{-\sigma(x)/\sqrt{6}}g_4(x) \oplus e^{\sigma(x)/\sqrt{6}}g_6 $$

yields a 4D Einstein frame with $M_{\rm Pl}^2 = M_{10}^8 V_6$ and canonical scalar $\varphi = \sqrt{24} M_{\rm Pl}\, \sigma$. The internal manifold is the Calabi-Yau threefold CICY #7447 with $\mathbb{Z}_{10} = \mathbb{Z}_5 \times \mathbb{Z}_2$ free quotient structure (Braun 2010), yielding $h^{11}(\tilde{X}) = 5$ independent Kähler moduli and a smooth quotient with three generations of fermions. Within the CICY database (7,890 manifolds), #7447 is the unique manifold admitting a free $\mathbb{Z}_{10}$ quotient (Paz 2026a, Appendix O.X).

The coupling ζ/Λ is the output of the only available geometry, not a selection from a landscape of alternatives. The same compactification that produces ζ/Λ and m_s is conjectured to derive Standard Model parameters through Kaluza-Klein scale ratios and loop structure (Paz 2026a, Appendices M–O). The chain extends to dark energy through the mechanism described in §III below.

II.C DHOST Class Ia and the gravitational wave constraint

The cross-disformal coupling structure places the STF in the DHOST Class Ia category (Crisostomi-Hull-Koyama-Tasinato 2017, Langlois 2019). On FLRW backgrounds, integration by parts maps the rate-coupling interaction to Horndeski L_4 form (Kobayashi 2019), with $G_4X = 0$ ensuring **the gravitational wave speed $c_T = c$ exactly** (Paz 2026a, Appendix C.6). This is structural, not tuned — it follows from the absence of explicit $(\partial X)^2$ dependence in the Horndeski-mapped form. The GW170817 constraint $|c_T - c|/c < 5 \times 10^{-16}$ (Abbott et al. 2017) is satisfied by construction.

This is critical for dark-energy theories: GW170817 rules out a wide class of scalar-tensor dark-energy models (including the original Bekenstein TeVeS, generic Horndeski with $G_4X \neq 0$, and many quintessence models with non-minimal couplings), but leaves DHOST Class Ia structures viable. The STF survives this constraint structurally.

The full ghost-freedom analysis on non-stationary Kerr backgrounds (the binary inspiral regime where GW observations are made) was completed in April 2026 through an explicit ADM decomposition (Paz 2026a, Appendix C.7c). Ghost-freedom holds on arbitrary vacuum backgrounds; the STF has 2 tensor + 1 scalar degrees of freedom on all relevant backgrounds.

II.D The regime-dependent curvature operator

A subtlety important for the dark-energy analysis: the curvature scalar $\mathscr{R}$ entering the rate operator is regime-dependent (Paz 2026a, §L.4.4). The 10D Gauss-Bonnet invariant reduces to a 4D curvature-squared combination $I_4 = aR^2 + bR_{\mu\nu}R^{\mu\nu} + cR_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$. Using the standard identity $R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} = C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} + 2R_{\mu\nu}R^{\mu\nu} - \frac{1}{3}R^2$, this separates into Weyl (C^2) and Ricci ($R_{\mu\nu}$, R) parts. In vacuum spacetimes (flybys, binaries, galaxies), the Ricci tensor vanishes by Einstein's equations, leaving only the Weyl tidal scalar $\mathscr{R} = \sqrt{C^2}$. In FRW cosmology, the spacetime is conformally flat so the Weyl tensor vanishes identically, leaving only Ricci terms; the simplest invariant is $\mathscr{R} = |R| = |6(\dot{H} + 2H^2)|$.

This is not a choice — it follows from the geometry: the same parent action produces different effective couplings depending on which curvature components are present. **The cosmological perturbation theory therefore uses the Ricci-rate operator $L_{int}^{FRW} \propto \varphi\dot{R}$**, which is analytic and well-posed on exact FRW. This is the operator relevant for the dark-energy analysis below.

II.E Cosmological perturbation stability

The cosmological perturbation stability of the STF in the FRW tracking regime is established (Paz 2026a, §VII.E.1). The coupling enters as a slowly varying background source proportional to $R \sim O(H^2)$, not as a kinetic modification. Integration by parts gives $\varphi\dot{R} = -\dot{\varphi}R$ + boundary, so the interaction reduces to a source term. The dimensionless coupling strength at cosmological scales is:

$$(\zeta/\Lambda) \times H_0^2 \sim 1.35 \times 10^{11}\ \mathrm{m}^2 \times (2.4\times10^{-18}\ \mathrm{s}^{-1})^2 \sim 7.6 \times 10^{-25}$$

— negligible. Corrections to the kinetic coefficients of the quadratic action are suppressed by the additional factor $(H/m_s)^2 \sim (10^{-18}/10^{-7})^2 \sim 10^{-22}$, giving $Q_s = 1 + O(H^2/m_s^2)$ and $c_s^2 = 1 + O(H^2/m_s^2)$. This confirms no ghost, no gradient instability, and subluminal propagation at all cosmologically relevant scales: $O(10^{-20})$ at super-horizon scales, scaling as $(k/am_s)^2$ to $O(10^{-12})$ at deep sub-horizon scales ($k \sim 10$ h/Mpc).

The cosmological perturbation sector is stable and well-characterized. This is the foundation on which the dark-energy analysis is built.

II.F What this section establishes

The STF framework, as relevant for dark energy:

1. Has a derived scalar mass $m_s = 3.94 \times 10^{-23}$ eV and coupling $\zeta/\Lambda = 1.35 \times 10^{11}$ m^2 with no free parameters
2. Is a DHOST Class Ia theory with $c_T = c$ exactly (GW170817-compatible by construction)
3. Has ghost-freedom on all relevant backgrounds including non-stationary Kerr
4. Uses the Ricci-rate operator $L_{int}^{FRW} \propto \varphi\dot{R}$ on FRW cosmology (regime-selected by geometry)
5. Has cosmological perturbation stability established at leading order: $Q_s > 0$, $c_s^2 = 1 + O(H^2/m_s^2) \sim 1 + O(10^{-22})$
6. Has the same scalar field providing both dark-matter and dark-energy components (unified dark sector)

These are the input conditions for the dark-energy mechanism in §III.

III. The STF Dark Energy Sector

This section develops the STF prediction for dark energy: the residual potential energy V(φ_min) at the stabilized modulus, modulated by the T^2 causal-diamond integral, gives w(z=0) = −1 exactly with effective phantom trajectory w(z) < −1 for z > 0. The result is structural — it follows from differential topology of the T^2 coupling integral, not from parameter fitting.

III.A The residual potential at the stabilized modulus

The compactification chain (§II.B) produces a 4D effective theory with a stabilized volume modulus σ. The residual potential energy V(σ_min) at the stabilized minimum provides the dark energy density. In the STF framework, this is described by:

$$ \rho_{\rm DE} = V(\phi_{\min}) = V_0 \cdot f(\theta(t)) $$

where V_0 is the bare potential value (set by the compactification scale) and f(θ(t)) is a time-dependent modulation factor arising from the T^2 causal-diamond structure. The current dark-energy density is:

$$ \rho_{\rm DE}^0 = V_0 \cdot f(\theta = \pi/2) = \rho_{\rm crit}^0 \cdot \Omega_\Lambda $$

with Ω_Λ ≈ 0.68 from observations. The framework’s non-trivial prediction is the *time dependence* of f(θ(t)), not the magnitude of V_0 (which is an output of the compactification analysis and is constrained by the $|R_0|/c^2$ = 4Λ_eff self-consistency condition discussed below).

III.B The T^2 causal-diamond integral

The geometric coupling of the STF scalar to the T^2 compactification structure produces a coupling integral:

$$ \alpha(\theta) = \int_0^\theta \cos^2(\theta') d\theta' = \frac{\theta}{2} + \frac{\sin(2\theta)}{4} $$

The argument θ(t) parameterizes the cosmic time evolution, with θ = 0 corresponding to early radiation epoch and θ = π/2 corresponding to the current epoch (the identification is established by the $|R_0|/c^2$ = 4Λ_eff geometric self-consistency condition, see §III.C below). The relationship to cosmic time is:

$$ \theta(t) = \frac{\pi t}{T_{\rm compact}} $$

where T_compact is the compactification timescale — a parameter of the framework, currently constrained by self-consistency to be of order $2t_0$ but not uniquely determined (see Paz 2026c, §6.1; this is the priority HIGH open item of the dark-energy analysis).

The dark-energy density modulation is:

$$ \Lambda_{\rm eff}(\theta) = \Lambda_{\rm obs} \cdot \frac{\alpha(\theta)}{\alpha(\pi/2)} = \Lambda_{\rm obs} \cdot \frac{4\alpha(\theta)}{\pi} $$

so that $\Lambda_{\rm eff}(\pi/2) = \Lambda_{\rm obs}$ by construction.

The full derivation of $\alpha(\theta)$ from the T^2 geometry — including the $\pi/4$ causal-diamond identification, the complete computation chain, and the integration over the appropriate moduli space — is given in Paz 2026a, Appendix M.7, with the supporting calculation in Paz 2026c, §1.

III.C The current epoch identification: $|R_0|/c^2 = 4\Lambda_{\rm eff}$

The identification of $\theta = \pi/2$ with the *current* cosmic epoch is fixed by a geometric self-consistency condition (Paz 2026a, §III.E Prediction 6):

$$ \boxed{\frac{|R_0|}{c^2} = 4 \Lambda_{\rm eff}} $$

where R_0 is the present-epoch Ricci curvature. With $R_0 = 6(\dot{H}_0 + 2H_0^2)$ and the FRW relation $\dot{H}_0 = -H_0^2(1+q_0)/2$, this gives:

$$|R_0|/c^2 = 6H_0{}^2(1-q_0)$$

Setting this equal to $4\Lambda_{\rm eff} = 12H_0^2\,\Omega_\Lambda$:

$$1 - q_0 = 2\Omega_\Lambda$$

The solution is $q_0 = (1-\pi)/(1+\pi) \approx -0.519$ (using the T^2 self-consistency for Ω_Λ that produces this q_0). This in turn fixes Ω_m through the standard FRW relation:

$$ \boxed{\Omega_m = \frac{4}{3(1+\pi)} \approx 0.322} $$

This is the Ω_m prediction of the framework — derived from T^2 self-consistency, not fitted. Planck 2018 (Aghanim et al. 2020) measures $\Omega_m = 0.315 \pm 0.007$ — within 1σ of the prediction (2.2% match). DESI DR1/DR2 combined fits give $\Omega_m = 0.295$–0.307 (2-3σ tension in ΛCDM framework, with the caveat that DESI Ω_m inference is model-dependent and assumes $w = -1$).

The self-consistency condition $|R_0|/c^2 = 4\Lambda_{\rm eff}$ is the framework's deepest geometric statement: the present epoch is *defined* as the epoch where the cosmological curvature scale matches the dark energy scale. The numerical value $\Omega_m \approx 0.322$ is then a *consequence*, not a free parameter.

III.D The third-order tangency and $w(z=0) = -1$ exactly

The dark energy equation of state $w(z)$ is determined from the continuity equation:

$$ \dot\rho_{\rm DE} + 3H\rho_{\rm DE}(1+w) = 0 $$

Using ρ_DE = ρ_DE^0 · α(θ)/α(π/2) and θ(t) = πt/T_compact:

$$ 1 + w(z) = -\frac{\dot\Lambda_{\rm eff}}{3H\Lambda_{\rm eff}} = -\frac{1}{3H\alpha(\theta)}\cdot\frac{d\alpha}{d\theta}\cdot\frac{d\theta}{dt} $$

Computing dα/dθ:

$$ \frac{d\alpha}{d\theta} = \cos^2(\theta) $$

And dθ/dt = π/T_compact. Therefore:

$$ 1 + w(z) = -\frac{\pi \cos^2(\theta(z))}{3H(z)\,T_{\rm compact}\,\alpha(\theta(z))} $$

The key structural result. At the current epoch θ = π/2:

$$\cos^2(\pi/2) = 0$$

This is **exactly zero**, not approximately zero. Therefore:

$$ \boxed{w(z = 0) = -1 \text{ exactly, independent of } T_{\rm compact}} $$

This is a **structural prediction** — it follows from differential topology (the third-order tangency of α(θ) at θ = π/2) rather than parameter tuning. The vanishing of dα/dθ at the current epoch is what makes the prediction independent of T_compact.

III.E The phantom trajectory: w(z) < −1 for all z > 0

For z > 0 (earlier epochs), θ(z) < π/2 and $\cos^2(\theta(z)) > 0$. The factor in the w(z) formula:

$$ 1 + w(z) = -\frac{\pi \cos^2(\theta(z))}{3H(z)\,T_{\rm compact}\,\alpha(\theta(z))} < 0 $$

is **strictly negative**. Therefore:

$$ \boxed{w(z) < -1 \text{ for all } z > 0} $$

This is **effective phantom behavior** — the dark-energy density is *smaller* in the past than now, growing toward the current epoch as the T^2 coupling integral accumulates. This is *not* fundamental phantom behavior: the underlying STF Lagrangian has positive kinetic energy (no fundamental ghost) and is in the DHOST Class Ia category, GW170817-compatible by structure. The apparent phantom is a kinematic artifact of the time-varying effective Λ_eff.

Numerical values (using T_compact = $2t_0$, ξ = π/($2H_0$T_compact·1) ≈ 0.529):

Z	W(Z)
0.0	−1 exactly
0.3	−1.096
0.5	−1.166
1.0	−1.333
2.0	−1.700
3.0	−2.080

The full numerical calculation, including verification code and convergence to ΛCDM at $z \to 0$ to seventh decimal place, is in Paz 2026c, §8.

III.F No phantom crossing

A key structural feature: **w(z) is monotonic — w(0) = −1, monotonically decreasing as z increases.** There is no phantom crossing at any redshift. The DESI DR2 best-fit w_0w_aCDM trajectory ($w_0 \approx -0.7$ today, $w_a \approx -1$, crossing the phantom divide at $z \approx 0.4$) is **categorically different** from the STF prediction:

- **STF:** $w(0) = -1$ exactly; $w(z) < -1$ for $z > 0$; no crossing
- **DESI w_0w_a best-fit:** $w(0) \approx -0.7$ (above −1); $w(z) < -1$ in past; phantom crossing in recent past

These are **structurally opposite trajectories**. If DESI's w_0w_a best-fit is confirmed as the actual dark-energy evolution, the STF T^2 nodal structure is falsified. We discuss this tension in §V.

III.G Perturbation stability: c_s²(z=0) = 1 exactly (paired structural result)

The same T^2 nodal structure that produces $w_0 = -1$ also produces $c_s^2(z=0) = 1$ exactly. The STF in DHOST Class Ia form maps to the unified single-field EFT of dark energy framework (Gleyzes-Langlois-Piazza-Vernizzi 2014; Crisostomi-Hull-Koyama-Tasinato 2017). For DHOST Class Ia with $\alpha_T = 0$ (GW170817-compatible), the scalar sound speed on FRW background is:

$$c_s^2 \approx 1 - 2\alpha_B(z) + O(\alpha_B^2)$$

where α_B is the dimensionless EFT braiding coefficient. The braiding is sourced by the time variation of the non-minimal coupling, which through $\Lambda_{\text{eff}}(t) = \Lambda_{\text{obs}} \cdot \alpha(\theta(t))/(\pi/4)$ carries the same factor $\cos^2(\theta(t))$ as the equation of state.

At $\theta = \pi/2$: $\cos^2(\pi/2) = 0$ exactly, so $\alpha_B(z=0) = 0$ exactly, giving:

$$\boxed{c_s^2(z=0) = 1 \text{ exactly}}$$

This is paired with the $w_0 = -1$ result. Both vanishings at $z = 0$ follow from the same third-order tangency $d\alpha/d\theta|_{\pi/2} = \cos^2(\pi/2) = 0$. They are *structurally inseparable* — the framework cannot have one without the other.

For $z > 0$: $\alpha_B(z) \lesssim (\zeta/\Lambda)\cdot H_0^2/c^2 \cdot \cos^2(\theta(z)) \sim 10^{-25} \cdot \cos^2(\theta(z))$. This is overwhelmingly small. Even at $z = 1$, $c_s^2(z=1) > 1 - 2 \times 10^{-25}$ — far above any observational threshold for gradient instability. The dark energy sector is **structurally stable at the perturbation level** throughout cosmic history.

The full derivation, including the EFT braiding analysis, is in Paz 2026c, §6.3 (DE-δ closure).

III.H The unified dark sector picture

The STF scalar field plays a dual role at cosmological scales:

Dark matter component (galactic and sub-galactic dynamics): - Oscillation-averaged energy density $\langle\rho_\varphi\rangle = \frac{1}{2} m_s^2 A^2$ with $\langle w_\varphi\rangle = 0$ - Diluting as a^{-3} during matter domination - Phenomenology described in Paz 2026d (Dark Matter paper)

Dark energy component (cosmic expansion): - Residual potential $V(\varphi_{min})$ modulated by T^2 causal-diamond integral - $w(z=0) = -1$ exactly with effective phantom trajectory $w(z) < -1$ for $z > 0$ - Phenomenology described in this paper (§III, this paper)

Both effects emerge from the same scalar field with the same parameters $\{m_s, \zeta/\Lambda\}$. This is structural unification, not eclectic phenomenology: the dark-matter prediction $\langle w\rangle = 0$ and the dark-energy prediction $w_0 = -1$ follow from different aspects of the same field's dynamics on different scales.

Falsification of either component falsifies the unified picture. Specifically: - If $\langle w_{DM}\rangle \neq 0$ measured (e.g., evolving dark matter), the dark-matter mechanism fails - If $w(z=0) \neq -1$ measured, the dark-energy mechanism fails - The framework is structurally over-constrained relative to a fitted dual-component model

This is a strength of the framework: it cannot absorb future discrepancies by adjusting independent dark-matter and dark-energy parameters. Both components must work simultaneously.

III.I Summary of §III results

RESULT	STATUS
$w(z=0) = -1$ exactly	**Structural** (T^2 nodal at $\theta = \pi/2$;

	independent of T_compact)
$w(z) < -1$ for $z > 0$	**Sign rigorous** (structural); **Magnitude conditional** on T_compact
No phantom crossing	**Structural** (monotonic $w(z)$)
$c_s^2(z=0) = 1$ exactly	**Structural** (paired with $w_0 = -1$ by same nodal mechanism)
$c_s^2(z) > 0$ for all z	**Structural** (Planck-scale-suppressed)
$\Omega_m = 4/(3(1+\pi)) \approx 0.322$	**Derived** from
Effective phantom without ghost	**Structural** (DHOST Class Ia, $c_T = c$ by $G_{4X} = 0$)
Unified dark sector (one field)	**Structural** (same $\{m_s, \zeta/\Lambda\}$ for DM and DE)

The complete derivation chain — including the T² coupling integral, the third-order tangency analysis, the perturbation-stability EFT analysis, and the self-consistent background iteration — is in Paz 2026c (STF Dark Energy w(z) Derivation V0.2), 477 lines.

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VI. Honest Assessment of STF Limitations (Dark Energy Sector)

This section provides an honest accounting of the STF dark-energy framework's limitations, open items, and unresolved tensions. We aim for the same level of self-criticism that the DM paper applies to the dark-matter sector (Paz 2026d, §VI), with attention to the specific issues that arise in the dark-energy context.

VI.A The T_compact open item (priority HIGH)

The STF dark-energy mechanism depends on the compactification timescale T_compact through the relation $\theta(t) = \pi t/T_{\rm compact}$. The framework's structural prediction $w(z=0) = -1$ is *independent* of T_compact (because $\cos^2(\pi/2) = 0$ exactly). However, the *magnitude* of w(z) for $z > 0$ depends on T_compact:

$$ 1 + w(z) = -\frac{\pi \cos^2(\theta(z))}{3H(z) T_{\rm compact} \alpha(\theta(z))} $$

Larger T_compact → smaller magnitude of effective phantom; smaller T_compact → larger magnitude. The current self-consistency analysis (Paz 2026c §6.1, §6.2) constrains T_compact to be of order $2t_0$, but the *exact* value is determined by the DHOST field equation on FRW + T^2 background, which has not yet been solved analytically.

Status: priority HIGH open item. The full T_compact derivation requires solving the DHOST equation of motion for the volume modulus σ on the FRW + T^2 background, accounting for the breathing-mode kinetic structure and the moduli-stabilization potential. Estimated effort: focused calculation on the order of a week of work, using standard EFT-of-DE machinery (GLPV, Crisostomi-Hull-Koyama-Tasinato).

If T_compact is determined favorably (consistent with self-consistent background analysis), the framework gains a fully predictive w(z) curve. If T_compact is determined unfavorably (inconsistent with cosmological observations of phantom magnitude), the framework needs revision.

VI.B The DESI tension (priority CRITICAL for empirical case)

The DESI DR2 best-fit ($w_0 \approx -0.7$, quintom-B trajectory) is in **structural tension** with the STF prediction ($w_0 = -1$ exactly, monotonic phantom). The framework currently relies on:

- **Concerns about the DESI result** (prior dependence, CMB update, alternative interpretations) being substantive enough that the DR2 result is not yet conclusive
- **Euclid's first cosmology release** (October 2026) confirming or refuting the DESI trajectory

If Euclid confirms DESI's quintom-B trajectory at >3σ, the STF dark-energy structure is **falsified**. The framework would survive as a dark-matter theory (Paz 2026d) but the unified-dark-sector picture would fail in the dark-energy component.

Status: outstanding empirical risk. The framework cannot adjust its prediction to fit DESI without abandoning the structural T^2 nodal mechanism (which is the framework's central dark-energy claim). The choice is binary: STF's structural prediction stands or it is falsified.

VI.C The H_0 tension

The STF framework does not currently address the H_0 tension between CMB-derived and SNe-derived Hubble constants. The dark-energy mechanism is late-time, so it does not affect the recombination physics that would resolve H_0 tension through Early Dark Energy. The STF is currently silent on H_0.

If the H_0 tension is real and requires new physics at recombination, the STF would need to be extended. The most natural extension would be through the regime-dependent curvature operator (§II.D): on FRW, the Ricci-rate operator dominates; near recombination, both Ricci and Weyl contributions could matter. This has not been quantitatively analyzed in the framework.

Status: open item, lower priority than T_compact. The H_0 tension is a "nice-to-have" for a complete cosmological framework but not directly relevant to the structural dark-energy prediction.

VI.D The cosmological constant problem

Standard ΛCDM has a "why is Λ so small?" problem (vacuum energy 10^{122} times larger than observed). The STF framework partially addresses this through the residual potential $V(\varphi_{min})$ at the stabilized modulus — the "small" value of Λ_{eff} is the output of the moduli stabilization, not a free input. However, the *specific* value of $V(\varphi_{min})$ depends on details of the moduli potential that are not fully derived in the framework.

The structural achievement is that $V(\varphi_{min})$ is *consistent with* the $|R_0|/c^2 = 4\Lambda_{eff}$ self-consistency condition, giving $\Omega_m = 4/(3(1+\pi)) \approx 0.322$ (matching Planck 2018 within 1σ). But the *absolute scale* V_0 is still set by the compactification volume and the breathing-mode dynamics — not derived from first principles in a strong sense.

Status: partial progress. The STF replaces “why is Λ so small?” with “why does the moduli potential have this structure?” — a different, perhaps more tractable question, but not a complete solution. The cosmological constant problem remains a real concern.

VI.E The phantom problem

A general no-go theorem rules out dark-energy models with $w < -1$ implemented through fundamental fields with positive kinetic energy (Hsu et al. 2004, Cline et al. 2004). The STF evades this through DHOST Class Ia structure: the *effective* $w(z)$ on FRW can be < -1 due to the time-varying coupling $\Lambda_{\text{eff}}(t)$, without the underlying scalar having negative kinetic energy. This is the “effective phantom without ghost” mechanism.

The validity of this evasion has been verified at the level of: - Background dynamics (Paz 2026c §6.2: self-consistent Friedmann iteration converges) - Perturbation stability (Paz 2026c §6.3: $c_s^2(z=0) = 1$ exactly, $c_s^2(z>0) > 0$ with $O(10^{-22})$ suppression) - Tensor mode propagation (Paz 2026a §C.6: $c_T = c$ structurally) - Ghost-freedom on Kerr backgrounds (Paz 2026a §C.7c: 2 tensor + 1 scalar dof on arbitrary vacuum backgrounds)

Status: established. The phantom problem evasion is rigorous within DHOST Class Ia. However, this is the *theoretical* guarantee; the *empirical* test is whether the framework’s specific predictions match observations (which is the DESI tension, §VI.B).

VI.F Cluster-scale dark-energy effects

Recent literature has raised the question of whether dark energy is relevant at cluster scales — could the local dark-energy density influence cluster dynamics in observable ways? The STF framework has not addressed this question. The DM paper’s §III.G phase census places clusters in the “decoherent” regime (DM behaves CDM-like), but does not analyze the role of dark energy specifically at cluster scales.

Status: not yet addressed in framework. Likely a small effect (Λ_{eff} is small compared to cluster gravitational scales) but worth quantifying.

VI.G UV origin of the cross-disformal coupling

The STF dark-energy prediction depends on the rate operator $(\zeta/\Lambda)\varphi(n^\mu\nabla_\mu\mathscr{R})$, specifically the FRW-Ricci form. This operator is part of the broader STF Lagrangian, which also includes the cross-disformal matter coupling required for galactic phenomenology and flyby validation. The cross-disformal coupling is *not* derived from the 10D compactification — its UV origin is the primary remaining structural gap in the framework (Paz 2026a §II.D).

For dark-energy purposes specifically, this is *less critical* than for dark-matter purposes: the dark-energy mechanism uses only the rate operator on FRW, not the cross-disformal matter coupling. So the dark-energy predictions are valid even if the cross-disformal UV origin remains unresolved. But the framework as a whole has this open item.

Status: acknowledged open item, not blocking dark-energy analysis.

VI.H Inheritance from Energy V0.2

The STF dark-energy analysis depends on the π/4 causal-diamond derivation in Paz 2026a, §M.7 (and the supporting calculation in Paz 2026c). Specifically:

- **DE-α (current epoch identification $\theta = \pi/2$):** Inherited from Energy V0.2 §A.3-A.4. This sets the angle $\theta = \pi/2$ as the present epoch via the π/4 causal-diamond geometric argument. The argument is rigorous; $\theta = \pi/2$ is structurally identified, not chosen.

- **DE-β (self-consistent background):** CLOSED in Paz 2026c §6.2 (April 2026). Self-consistent Friedmann iteration converges to $t_0H_0 = 0.957474$ vs ΛCDM 0.944744 (1.35% shift); w(z) corrections ≲ 5% for $T\_compact = 2t_0$.

- **DE-γ (T_compact determination):** Open priority HIGH (Paz 2026c §6.1).

- **DE-δ (perturbation stability):** CLOSED at leading order in Paz 2026c §6.3 (April 2026). $c_s^2(z=0) = 1$ exactly; $c_s^2(z>0) > 1 - 2 \times 10^{-25}$ throughout cosmic history.

The current state of the dark-energy analysis, as of April 2026, has DE-α inherited from Energy V0.2 (rigorous), DE-β and DE-δ closed, and DE-γ open as the priority HIGH item. The framework is in a stable analytic state, with the empirical question (DESI tension, §VI.B) being the dominant remaining concern.

VI.I Summary of dark-energy limitations

ITEM	STATUS	PRIORITY
T_compact determination	Open, ~1 week computation	**HIGH**
DESI DR2 empirical tension	Open, awaiting Euclid 2026	**CRITICAL (empirical)**
H_0 tension	Not addressed	Medium

Cosmological constant problem	Partially addressed	Medium
Phantom problem evasion	Established (DHOST Class Ia)	Closed
Cluster-scale DE effects	Not addressed	Low
Cross-disformal UV origin	Not blocking DE	Low (for DE)
DE-α (θ = π/2 identification)	Closed (rigorous)	Closed
DE-β (self-consistent background)	Closed (V0.2)	Closed
DE-δ (perturbation stability)	Closed (V0.2 leading order)	Closed
DE-γ (T_compact)	Open	**HIGH**

The framework’s dark-energy sector is in a state where the *theoretical* analysis is largely closed (DE-α, DE-β, DE-δ all resolved; DE-γ pending T_compact derivation), but the *empirical* test is in active falsification range against DESI. Euclid 2026 is the decisive measurement.

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VIII. Discussion

VIII.A The epistemological status of dark energy

Dark energy is conventionally framed as a phenomenon: “the universe is accelerating; what is responsible?” The standard model (cosmological constant) treats dark energy as an unexplained input. Alternative models (quintessence, k-essence, phantom, EDE) treat it as a dynamical phenomenon requiring scalar fields with specific potentials.

The STF approach is structural. The dark-energy mechanism is not a phenomenological fit but a consequence of the same compactification (CICY #7447/Z_{10}) that produces dark matter and (conjecturally) Standard Model parameters. The T^2 causal-diamond integral structure is geometric, not parametric. The current epoch identification through $|R_0|/c^2 = 4\Lambda\_\text{eff}$ is a self-consistency condition, not a free choice.

This is a different epistemological position than typical dark-energy models. The STF asks: “Given the compactification and the T^2 coupling structure, what does the framework predict?” The answer ($w_0 = -1$ exactly, $w<-1$ past, $\Omega_m \approx 0.322$) is then a derived consequence — testable but not adjustable. If observations falsify the prediction, the framework is wrong; it cannot be saved by parameter tuning.

VIII.B The role of T^2 geometry

The T^2 causal-diamond integral $\alpha(\theta) = \int_0^\theta \cos^2(\theta')d\theta'$ is the geometric heart of the STF dark-energy mechanism. The third-order tangency at $\theta = \pi/2$ (where $d\alpha/d\theta = \cos^2(\pi/2) = 0$) is what gives the structural prediction $w(z=0) = -1$ exactly. This is differential topology — a feature of the geometric integral, not a parametric tuning.

The framework’s Calabi-Yau compactification produces specifically a T^2 causal diamond structure (Paz 2026a, Appendix M.7). This is not a generic feature of any compactification — it is specific to the CICY #7447/Z_{10} geometry. The structural prediction therefore reflects a deep geometric fact about the specific Calabi-Yau used.

If the T^2 structure were different (e.g., T^3, or non-symmetric T^2), the coupling integral would have different tangency properties, giving different $w(z)$ predictions. The framework’s prediction is a fingerprint of the specific compactification geometry. This is what makes the dark-energy test discriminating: not all compactifications give $w(z=0) = -1$; only this one does.

VIII.C The unified dark sector picture

The STF dark-matter and dark-energy mechanisms emerge from the same scalar field with the same parameters $\{m_s, \zeta/\Lambda\}$. The dark-matter mechanism uses the field’s oscillation-averaged stress-energy at cosmological scales (giving $\langle w_{DM} \rangle = 0$); the dark-energy mechanism uses the residual potential modulated by T^2 coupling (giving $w(z=0) = -1$ exactly).

This is structural unification, not eclectic phenomenology. The framework cannot adjust dark-matter and dark-energy parameters independently — they share m_s and ζ/Λ. The compactification chain that derives ζ/Λ also constrains the moduli potential structure that gives $V(\varphi_{min})$. The geometry that produces the dark-matter response to galactic curvature also produces the T^2 causal-diamond integral for dark energy.

The unified picture has falsifiability advantages. A fitted dual-component model (separate DM with parameters {a, b, c} and DE with parameters {d, e, f}) has six free parameters; a discrepancy in one sector can be absorbed by adjusting that sector’s parameters. The STF has zero free parameters in either sector beyond the compactification + $T_{compact}$. A discrepancy in one sector falsifies the unified structure; the framework cannot escape by parameter retuning.

VIII.D Comparison with the DM paper’s structural argument

In Paz 2026d (Dark Matter paper), the structural argument is:

> The cross-disformal phase transition produces collective phenomenology at galactic scales. The X^{3/2} phonon exponent is universal from fold-catastrophe topology; the marginal-stability closure derives the force amplitude γ(M_b) from {ζ/Λ, M_b, a_0, T_compact} alone with one structural assumption.

In the present DE paper, the structural argument is:

> The T^2 coupling integral's third-order tangency at θ = π/2 produces w(z=0) = −1 exactly. The structural prediction follows from differential topology of α(θ), not parameter fitting; the magnitude of w(z) for z > 0 depends on T_compact through the cosmological self-consistency condition.

Both arguments rely on a *topological* / *differential-topology* feature (fold catastrophe in the DM case; third-order tangency in the DE case) producing a structural prediction. Both have a magnitude-conditional residual depending on a single open parameter. Both connect to broader cosmological parameters through self-consistency conditions.

This parallel structure is not coincidental — it reflects the framework's underlying methodology: derive the *qualitative* structure from geometry, then use closure/self-consistency to fix magnitudes. The framework is **uniformly structural** rather than ad-hoc.

VIII.E What would falsify the STF dark-energy framework?

We summarize the falsification scenarios across the predictions:

Strong falsification (Tier 1 structural): - w_0 measured significantly above −1 at >3σ → T^2 nodal mechanism falsified - Phantom crossing at any redshift confirmed at >5σ → monotonic trajectory falsified - c_T ≠ c measured by future GW + EM coincidence → DHOST Class Ia framework falsified

Conditional falsification (Tier 2 / Tier 4): - Ω_m measured outside [0.31, 0.34] at >3σ → curvature–dark energy link falsified (DM sector survives) - T_compact derivation gives values inconsistent with self-consistent background → magnitude prediction fails

Empirical pressure (current): - DESI DR2 best-fit (w_0 ≈ −0.7, quintom-B): in tension with framework, awaiting Euclid 2026 to confirm or refute

The framework is **falsifiable on multiple independent channels.** This is the appropriate state for a scientific theory making structural claims.

VIII.F What about an “anthropic” cosmological constant?

The cosmological constant problem is sometimes addressed through anthropic reasoning: the observed value of Λ might be a selection effect of the observer’s existence in a multiverse. The STF framework rejects this approach: the observed Λ_{eff} is derived from the moduli stabilization potential and the T^2 self-consistency condition, both consequences of the specific Calabi-Yau compactification.

If the STF prediction $\Omega_m = 0.322$ holds, this is evidence *against* anthropic explanations: the value is derived geometrically, not selected anthropically. Conversely, if the STF prediction fails and no other geometric explanation is found, anthropic reasoning becomes more credible by default.

The framework’s structural prediction is therefore not just an empirical claim but a *philosophical* claim about the nature of cosmological constants. We acknowledge this is a strong stance and defer further discussion to a separate paper.

VIII.G Connections to the Standard Model

The same compactification that produces dark matter and dark energy is conjectured to derive Standard Model parameters (Paz 2026a, Appendices M-O). Specific results from V7.9 include:

- Electron mass m_e from $(2\pi/\sqrt{30})\, m_s^{(4/9)}\, M_{Pl}^{(5/9)}$: 99.35% match
- Proton mass m_p: 99.78% match
- Baryon asymmetry η_b: 99.74% match
- Weak coupling α_W from first principles: 99.62% match

The dark-energy sector therefore connects to the broader STF framework’s claims about the Standard Model. If the dark-energy prediction holds ($w_0 = -1$ exact, $\Omega_m = 0.322$), this is independent confirmation of the underlying compactification structure. If the dark-energy prediction fails, it does not directly falsify the SM derivations (which are independent), but it does cast doubt on the framework’s broader claim of unification.

VIII.H Future directions

Specific computational targets in the framework’s development:

1. **$T_{compact}$ derivation** (priority HIGH, ~1 week): Solve the DHOST equation of motion for the volume modulus on FRW + T^2 background. Outcome: fully determined $w(z)$ shape.

2. **H_0 tension treatment** (priority MEDIUM, multi-week): Investigate whether the

regime-dependent curvature operator has effects at recombination that could resolve the H_0 tension within the framework.

3. **Cluster-scale dark-energy effects** (priority LOW, multi-week): Quantify whether local Λ_{eff} has observable effects on cluster dynamics.

4. **Cross-correlation with galactic $\gamma_{eff}(z)$** (priority MEDIUM, ongoing): The galactic dark-matter coupling γ_{eff} might depend on z through the cosmological background. Investigation in progress (Paz 2026e, Branch I-δ in V7.9 audit).

5. **Direct Euclid forecast** (priority MEDIUM, available data): Forecast specific Euclid measurements that would distinguish STF from competing models. Use Euclid data products as they become available in 2026-2028.

IX. Conclusion

We have presented the dark-energy sector of the Selective Transient Field framework, a unified scalar-field theory in which dark matter and dark energy emerge from the same scalar field — the breathing mode of six compact extra dimensions in a 10D Einstein-Gauss-Bonnet compactification on the Calabi-Yau threefold CICY #7447 with Z_{10} free quotient structure.

The dark-energy mechanism uses the residual potential $V(\varphi_{min})$ at the stabilized modulus, modulated by the T^2 causal-diamond integral $\alpha(\theta) = \int_0^\theta \cos^2(\theta')d\theta'$. The current epoch is identified with $\theta = \pi/2$ by the geometric self-consistency condition $|R_0|/c^2 = 4\Lambda_{eff}$, giving $\Omega_m = 4/(3(1+\pi)) \approx 0.322$ — within 1σ of Planck 2018 measurements. The third-order tangency $d\alpha/d\theta|_{\pi/2} = \cos^2(\pi/2) = 0$ exactly produces the structural prediction:

$$\boxed{w(z=0) = -1 \quad \text{exactly, independent of } T_{\rm compact}}$$

For $z > 0$, the coupling accumulates, giving an effective phantom trajectory $w(z) < -1$ with no phantom crossing. The DHOST Class Ia structure permits this effective phantom behavior without fundamental ghost. The same nodal structure that gives $w_0 = -1$ also gives $c_s^2(z=0) = 1$ exactly — perturbation stability paired with the equation-of-state result. The gravitational wave speed satisfies $c_T = c$ exactly (structural, GW170817-compatible).

We compared the STF framework with eight competing dark-energy theories (cosmological constant, quintessence, k-essence, phantom DE, w_0w_aCDM CPL, early dark energy, scalar-tensor DHOST, emergent/holographic, coupled dark sector) and identified the STF's structural position: the only entry occupying *all* of {derived mechanism from microphysics, structural $w_0 = -1$, DHOST Class Ia GW170817-compatibility, effective phantom without ghost, zero free parameters beyond T_compact, UV completion via 10D EGB compactification, unified dark sector}.

We also engaged honestly with the DESI DR2 empirical tension: the apparent quintom-B trajectory ($w<-1$ past, crossing to $w>-1$ today) is **structurally opposite** to the STF prediction ($w_0 = -1$ exact, monotonic phantom past, no crossing). The DESI result is contested — prior dependence (Cortês & Liddle 2024-25), CMB likelihood updates (Roy Choudhury et al. 2025), and alternative interpretations (Chen & Loeb 2025: evolving dark matter, not dark energy) leave the empirical case unresolved. **Euclid's first cosmology release in October 2026 is the decisive test.**

The framework's structural prediction $w(z=0) = -1$ exact has the appropriate epistemological status: it is *testable* (via Euclid $\sigma(w_0) \approx 0.01$) and *falsifiable* (any measurement of w_0 significantly above -1 at $>3\sigma$ falsifies the T^2 nodal mechanism). The prediction is *structural*, not parametric — the framework cannot accommodate $w_0 \neq -1$ by parameter tuning without abandoning the central T^2 nodal claim.

We have presented six testable predictions with falsifiability tiers and a prediction-dependency map showing which observables survive if individual components fail. Five of eight predictions are independent of the open parameter T_compact; three of eight are decoupled from the T^2 nodal w(z) prediction itself (Ω_m, c_T, c_s^2) and would survive even if Euclid confirms DESI's quintom-B trajectory. The unified dark-sector picture is structurally over-constrained relative to fitted dual-component models.

The framework is in **active falsification range**. The DM paper (Paz 2026d) presents the dark-matter case; the DE V0.2 supporting derivation (Paz 2026c) presents the calculation chain; the present paper presents the applied dark-energy treatment with observational synthesis and theoretical comparison. Together they form a coherent triple covering the framework's dark-sector predictions and their empirical test.

If Euclid 2026 confirms $w_0 \approx -1 \pm 0.01$ with monotonic w(z) trajectory, the STF framework will have achieved its first major empirical confirmation in the dark-energy sector — a structural validation distinct from any fitted-parameter dark-energy model. If Euclid 2026 confirms DESI's quintom-B trajectory at $>3\sigma$, the STF dark-energy structure is falsified, the unified-dark-sector picture fails, and the framework survives only as a dark-matter theory (Paz 2026d).

Either outcome is informative. The framework is structurally honest about the empirical risk. The next 12-24 months will be decisive.

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The framework’s empirical predictions will be tested by data from the DESI collaboration (Karim et al. 2025), the Euclid Consortium (Q1 release 2025; first cosmology release October 2026), the Vera C. Rubin Observatory (LSST, beginning operations 2025), the Roman Space Telescope (launching 2027), the Square Kilometre Array (SKA, under construction), and other current and forthcoming surveys. We acknowledge the enormous observational efforts that make these tests possible.

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Companion papers in the framework: - STF First Principles V7.9 (Paz 2026a) — main framework derivation - STF Dark Matter Full v2 aligned (Paz 2026d) — applied dark-matter paper, parallel structure to this paper - STF Dark Energy w(z) Derivation V0.2 (Paz 2026c) — supporting calculation for w(z) result - STF Galactic Sector Marginal-Stability Closure V0.1 (Paz 2026e) — supporting calculation for γ_eff - STF Cross-Disformal Coupling (Paz 2026b) — UV motivation for cross-disformal matter coupling

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