The Phantom Problem

Theoretical Pathologies in DESI DR2 Dark Energy Claims

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Abstract

The Dark Energy Spectroscopic Instrument (DESI) collaboration has reported evidence for evolving dark energy with equation of state parameters $w_0 = -0.752 \pm 0.057$ and $w_a = -0.861 \pm 0.222$, interpreted as significant tension with the cosmological constant (ΛCDM). We present three independent lines of evidence that this claimed detection is problematic. First, statistical analysis of the DESI posterior reveals that the model-independent constraint at the pivot redshift $z \approx 0.31$ is $w = -0.954 \pm 0.024$, only 1.9σ from $w = -1$, with the 95% credible interval including the ΛCDM value. The apparent high significance arises from the strong w_0-w_a anti-correlation ($\rho = -0.91$) inherent to the CPL parametrization. Second, multiple independent analyses have identified systematic concerns: the signal disappears with alternative supernova samples (Efstathiou 2025), vanishes upon excluding single data points (Dinda et al. 2024), and may be a parametrization artifact (Giarè et al. 2024). Third, and most critically, the DESI best-fit implies phantom behavior ($w < -1$) at $z > 0.4$ in 99.9% of the posterior. Phantom dark energy requires negative kinetic energy—a ghost degree of freedom leading to vacuum instability and unbounded Hamiltonian. No ghost-free field theory can produce DESI's $w(z)$ trajectory. The claimed detection is therefore either a statistical/systematic artifact or evidence for physics that violates fundamental stability requirements. The theoretical prior strongly favors $w = -1$.

I. Introduction

The nature of dark energy remains one of the central problems in cosmology. The simplest explanation—a cosmological constant Λ with equation of state $w = -1$—has remained consistent with all observations for over two decades, yet lacks theoretical motivation from fundamental physics. The possibility that dark energy evolves with redshift has driven major observational programs aimed at detecting deviations from $w = -1$.

The Dark Energy Spectroscopic Instrument (DESI) collaboration recently reported their Year 1 baryon acoustic oscillation (BAO) measurements combined with cosmic microwave background (CMB) and Type Ia supernova (SNe) data [1]. Fitting to the Chevallier-Polarski-Linder (CPL) parametrization $w(a) = w_0 + w_a(1-a)$, they report:

$$w_0 = -0.752 \pm 0.057, \quad w_a = -0.861 \pm 0.222$$

This has been widely interpreted as evidence for "evolving dark energy" at high statistical significance, with some analyses claiming tension with ΛCDM exceeding 5σ.

In this paper, we argue that this interpretation is problematic on three independent grounds:

1. **Statistical**: The apparent significance is inflated by parametrization artifacts; at the model-independent pivot redshift, the constraint is only 1.9σ from w = -1.

2. **Systematic**: Multiple independent analyses have identified calibration issues, statistical fragility, and parametrization dependence.

3. **Theoretical**: The DESI best-fit requires phantom dark energy ($w < -1$), which cannot be realized by any stable field theory.

The theoretical argument is particularly decisive: even if the statistical and systematic concerns were resolved, the physics required to explain DESI's claimed w(z) evolution is pathological. This places a strong theoretical prior on w = -1 that must be weighed against any observational claim to the contrary.

II. Statistical Analysis of DESI DR2 Posterior

II.1 Data and Methodology

We performed an independent analysis of the publicly available DESI MCMC chains from the w_0w_aCDM fit combining BAO, CMB (Planck + ACT), and Type Ia supernovae (DESY5). The dataset comprises 61,168 samples with approximately 37,000 effective samples after accounting for chain weights.

II.2 Posterior Statistics

The weighted posterior mean and standard deviation are:

Parameter	Mean	Std
w_0	-0.752	0.057
w_a	-0.861	0.222

The correlation coefficient between w_0 and w_a is:

$$\rho(w_0, w_a) = -0.907$$

This extreme anti-correlation is not a feature of the data—it is intrinsic to the CPL parametrization and creates a strong degeneracy that inflates apparent tension with any constant-w model.

II.3 The Pivot Redshift

The CPL parametrization $w(a) = w_0 + w_a(1-a)$ creates an inherent degeneracy between w_0 and w_a. At a specific "pivot" redshift, this degeneracy is minimized and the constraint becomes model-independent.

The variance of w(a) is:

$$\sigma^2[w(a)] = \sigma_{w_0}^2 + 2(1-a)\mathrm{Cov}(w_0, w_a) + (1-a)^2\sigma_{w_a}^2$$

Minimizing with respect to a:

$$a_p = 1 + \frac{\mathrm{Cov}(w_0, w_a)}{\sigma_{w_a}^2} = 0.766$$

This corresponds to pivot redshift z_p = 0.31.

At the pivot redshift:

$$w(z_p) = -0.954 \pm 0.024$$

The distance from w = -1:

$$\frac{w(z_p) - (-1)}{\sigma[w(z_p)]} = \frac{0.046}{0.024} = 1.9\sigma$$

The 95% credible interval is **[-1.001, -0.906]**, which **includes w = -1**.

This is the model-independent constraint. The DESI data are consistent with w = -1 at the 2σ level.

II.4 Two-Dimensional Significance

The proper measure of tension between a point prediction and a 2D posterior is the Mahalanobis distance:

$$D_M^2 = (\mathbf{x} - \boldsymbol{\mu})^T \Sigma^{-1} (\mathbf{x} - \boldsymbol{\mu})$$

For the ΛCDM point (w_0 = -1, w_a = 0):

$$D_M^2 = 18.71$$

For a χ^2 distribution with 2 degrees of freedom, this corresponds to $p = 8.7 \times 10^{-5}$, or equivalently **3.9σ**.

This is below the 5σ discovery threshold and substantially less than headline claims of "5.8σ" or similar, which likely arise from incorrectly treating w_0 and w_a as independent measurements.

II.5 Summary of Statistical Tests

Test	Result	Significance
Pivot redshift ($z = 0.31$)	$w = -0.954 \pm 0.024$	1.9σ from -1
95% CI at pivot	[-1.001, -0.906]	**Includes -1**
2D Mahalanobis	$\chi^2 = 18.7$	3.9σ
Posterior fraction with $w_0 < -1$	0.0%	—
Posterior fraction requiring phantom	99.9%	See Section IV

The statistical evidence for $w \neq -1$ is substantially weaker than headlines suggest. At the model-independent pivot redshift, the 95% credible interval includes $w = -1$.

III. Systematic Concerns

Multiple independent analyses have raised serious concerns about the robustness of the DESI dark energy signal.

III.1 Supernova Sample Dependence

Efstathiou [2] demonstrated that the preference for evolving dark energy is strongly dependent on the supernova sample used. When DESI BAO data are combined with the Pantheon+ supernova compilation instead of DESY5, the signal for $w \neq -1$ largely disappears and results become consistent with ΛCDM.

Efstathiou identifies a 0.04-0.06 magnitude offset between low and high redshift supernovae in DESY5, attributable to calibration systematics rather than new physics. The conclusion is stark: the claimed detection depends on which supernova dataset is used, indicating that systematic errors in SNe calibration may be driving the signal.

III.2 Statistical Fragility

Dinda et al. [3] applied a model-independent null test to the DESI data and found “no strong evidence for dynamical dark energy.” More concerning, they demonstrated that excluding the single BAO measurement at $z = 0.51$ largely eliminates the evolving dark energy signal.

When a claimed detection can be erased by removing one data point out of several, the result is statistically fragile and should not be interpreted as robust evidence for new physics.

III.3 Parametrization Artifacts

Giarè et al. [4] showed that the “phantom crossing” implied by the DESI w_0-w_a fit—where w transitions from $w > -1$ at low redshift to $w < -1$ at high redshift—may be an artifact of the CPL parametrization’s forced linear evolution in scale factor.

They demonstrate that thawing quintessence models, which by construction have $w \geq -1$ at all times, fit the DESI data comparably well. The apparent phantom behavior is therefore not required by the data; it is imposed by the parametrization choice.

III.4 Assessment

Three independent groups using different methodologies have identified concerns:

- The signal depends on SNe sample choice (systematic)
- The signal depends on single data points (statistical fragility)
- The signal depends on parametrization (model dependence)

This does not prove DESI is wrong, but it establishes that the claimed detection is not robust and should be treated with appropriate caution.

IV. The Theoretical Problem: Phantom Dark Energy

The most serious problem with DESI's claimed detection is theoretical. Even setting aside statistical and systematic concerns, the physics required to produce DESI's w(z) trajectory is pathological.

IV.1 The DESI Best-Fit Trajectory

The CPL best-fit parameters imply an equation of state evolution:

$$w(z) = w_0 + w_a \frac{z}{1+z}$$

With $w_0 = -0.752$ and $w_a = -0.861$:

Redshift	w(z)	Regime
z = 0.0	-0.75	Quintessence (w > -1)
z = 0.4	-1.00	Crosses cosmological constant
z = 0.5	-1.04	Phantom (w < -1)
z = 1.0	-1.18	Deep phantom
z = 2.0	-1.33	Deep phantom

The trajectory crosses w = -1 at z ≈ 0.4. For all z > 0.4, the equation of state is in the "phantom" regime.

IV.2 Prevalence in the Posterior

This is not a feature of the best-fit alone. We computed $w(z=1) = w_0 + 0.5w_a$ for each MCMC sample:

99.9% of the posterior requires w < -1 at z = 1.

Phantom behavior is not an edge case—it is demanded by essentially the entire DESI posterior.

IV.3 What Phantom Dark Energy Requires

For a canonical scalar field with Lagrangian:

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V(\phi)$$

the equation of state is:

$$w_\phi = \frac{\frac{1}{2}\dot{\phi}^2 - V}{\frac{1}{2}\dot{\phi}^2 + V}$$

Since kinetic energy is positive definite, we have:

$$\rho + p = \dot{\phi}^2 \geq 0$$

This means w ≥ -1 always for any canonical scalar field. This is a consequence of the null energy condition.

To achieve w < -1 requires **negative kinetic energy**:

$$\mathcal{L}_{\text{phantom}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi)$$

The wrong sign in front of the kinetic term defines a "ghost" field. (See Appendix C for discussion of effective phantom behavior in broader frameworks and why these do not generically evade the stability concern.)

IV.4 Why Ghosts Are Catastrophic

Ghost fields are not merely exotic—they are theoretically pathological:

1. Unbounded Hamiltonian

The Hamiltonian for a ghost field is:

$$H = -\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}(\nabla\phi)^2 + V(\phi)$$

The kinetic contribution is negative, making H unbounded from below. The system has no ground state.

2. Vacuum Instability

A ghost can decay into positive-energy particles plus ghost quanta (which carry negative energy) while conserving total energy. The rate for this process is infinite when integrated over phase space. The vacuum decays instantaneously.

3. Ostrogradsky Instability

In any interacting theory containing a ghost, Ostrogradsky's theorem guarantees that the Hamiltonian is linear in at least one canonical momentum. This leads to classical runaway solutions and quantum vacuum decay.

4. Observational Contradiction

If phantom dark energy existed, the universe would have decayed into a bath of high-energy particles and ghost quanta long ago. We would not be here to observe DESI data.

IV.5 Attempted Escapes

Several theoretical mechanisms have been proposed to evade the phantom problem:

Quintom (two-field) models: These introduce both a quintessence field ($w > -1$) and a phantom field ($w < -1$), allowing crossing. But the phantom component remains a ghost.

k-essence / non-canonical kinetics: These can achieve $w < -1$ in certain limits, but typically at the cost of gradient instabilities or superluminal propagation.

Modified gravity: The "effective w" reconstructed from H(z) can cross -1 without a phantom field, but post-GW170817 constraints (gravitational wave speed = c) severely limit this possibility.

Interacting dark energy: Energy exchange between dark energy and dark matter can produce effective $w < -1$, but typically requires fine-tuning and faces structure formation constraints.

None of these provides a theoretically satisfactory explanation for DESI's w(z) trajectory. The phantom crossing at $z \approx 0.4$ with deep phantom behavior at $z > 0.5$ remains problematic.

IV.6 The Mass Scale Argument

There is an additional theoretical constraint from the scalar field mass scale.

For a scalar field with mass m in an expanding universe with Hubble parameter H, the equation of state deviation from $w = -1$ scales as:

$$1 + w \sim \left(\frac{H}{m}\right)^2$$

To achieve $|1 + w| \sim 0.25$ (as DESI requires at $z = 0$), we need:

$$\frac{H_0}{m} \sim 0.5 \implies m \sim 2H_0 \sim 3 \times 10^{-33} \text{ eV}$$

This is an extraordinarily light mass—comparable to the Hubble scale itself. Such ultra-light scalars face severe constraints from fifth-force experiments and equivalence principle tests unless they are screened or couple only gravitationally.

For comparison, typical particle physics scales: - Neutrino mass: ~ 10^{-2} eV - Axion (QCD): ~ 10^{-5} eV - Required for DESI: ~ 10^{-33} eV

A 30 order-of-magnitude gap from even the lightest known particles.

IV.7 What Healthy Physics Predicts

Any theoretically healthy dark energy model with scalar mass m >> H predicts:

$$w = -1 + \mathcal{O}\left(\frac{H^2}{m^2}\right) \approx -1$$

The deviation is suppressed by the ratio $(H/m)^2$. For any m >> H_0:

Scalar mass	$(H_0/m)^2$	Predicted w
m ~ 10^{-23} eV	10^{-20}	-1 + 10^{-20}
m ~ 10^{-15} eV	10^{-36}	-1 + 10^{-36}
m ~ 1 eV	10^{-66}	-1 + 10^{-66}

All healthy scalar field theories with m >> H predict w = -1 to extraordinary precision.

The only way to achieve observable w ≠ -1 is: 1. m ~ H (ultra-light, fine-tuned, constrained), or 2. Ghost (pathological)

This places a strong theoretical prior on w = -1.

Concrete realization — STF framework: The Selective Transient Field (GW170817-compatible by calculation on its Gauss–Bonnet route, $|c_T/c - 1| \lesssim 10^{-30}$; the former DHOST Class Ia label is withdrawn — V8.1 App. P) provides a specific no-further-fit derivation of w(z=0) = −1 rather than a prior. The T^2 coupling integral $\alpha(\theta) = \int_0^\theta \cos^2\theta' d\theta'$ has a third-order tangency at the current epoch (θ = π/2): $d\alpha/d\theta|_{\pi/2} = \cos^2(\pi/2) = 0$. The rate of change of the coupling vanishes exactly at z = 0, forcing $\dot{\Lambda}_{eff} = 0$ and therefore w(z=0) = −1 independent of all free parameters. The field mass is $m_s = 3.94 \times 10^{-23}$ eV >> $H_0 \sim 10^{-33}$ eV, placing it in the m >> H regime of the table above (predicted deviation $|1+w| \sim 10^{-20}$, consistent). The STF trajectory — w = −1 at z = 0, monotonically phantom at higher z from T^2 coupling accumulation, no crossing from above — is categorically different from the DESI CPL best-fit ($w_0 = -0.752$, crossing at z ≈ 0.4). A theory that derives $w_0 = -1$ exactly from topology, predicts a specific phantom history without a ghost, and whose trajectory shape disagrees with DESI's claimed trajectory — is precisely the kind of stable microphysical alternative that the theoretical prior argument is pointing toward. See Appendix C.2 and STF Energy V0.3 §VIII for the complete derivation.

V. Discussion

V.1 The Hierarchy of Evidence

We have presented three independent arguments against the DESI dark energy detection:

Argument	Strength	Conclusion
Statistical	Moderate	1.9σ at pivot, 95% CI includes -1
Systematic	Strong	Signal depends on SNe sample, single points, parametrization
Theoretical	Decisive	Required physics is pathological (ghost)

These arguments are independent. Even if the statistical analysis were somehow flawed, and even if all systematic concerns were resolved, the theoretical argument remains: **DESI's w(z) requires phantom dark energy, which cannot exist in any stable field theory.**

V.2 Theoretical Priors in Cosmology

Observational claims must be weighted against theoretical priors. The history of physics provides guidance:

- Faster-than-light neutrinos (OPERA 2011): Extraordinary claim, later found to be systematic error
- BICEP2 gravitational waves (2014): Extraordinary claim, later found to be dust contamination
- Dark energy evolution (DESI 2024): Extraordinary claim, requiring pathological physics

When an observation requires physics that violates fundamental principles (in this case, vacuum stability), the appropriate response is skepticism pending extraordinary confirmation.

V.3 The Path Forward

Definitive tests of dark energy evolution require:

1. **Independent BAO measurements**: Euclid (operating), DESI continued observations
2. **Resolved SNe systematics**: Understanding DESY5 vs Pantheon+ discrepancy
3. **Model-independent reconstruction**: Moving beyond CPL to non-parametric methods
4. **Growth rate constraints**: $f\sigma_8$ measurements that test both background and perturbations

If future data confirm $w \neq -1$ at high significance across multiple independent probes with resolved systematics, the theoretical community will face a profound challenge. But that threshold has not been met.

V.4 What the Data Actually Show

A fair summary of current evidence:

- DESI BAO data prefer $w_0 > -1$ in CPL fits
- This preference depends on SNe sample choice
- At the model-independent pivot redshift, $w = -0.954 \pm 0.024$
- The 95% credible interval includes $w = -1$
- The best-fit requires phantom behavior, which is theoretically pathological
- Independent analyses have identified statistical fragility and parametrization artifacts

The data are consistent with $w = -1$. The claimed detection of evolution is not robust.

VI. Conclusion

The DESI DR2 claim of evolving dark energy faces three independent challenges:

Statistical: At the model-independent pivot redshift $z \approx 0.31$, the constraint $w = -0.954 \pm 0.024$ is only 1.9σ from $w = -1$. The 95% credible interval includes the cosmological constant value. The apparent high significance arises from the w_0-w_a correlation (-0.91) inherent to the CPL parametrization.

Systematic: The signal disappears with alternative supernova samples (Efstathiou 2025), vanishes upon excluding single data points (Dinda et al. 2024), and may be a parametrization artifact (Giarè et al. 2024). The detection is not robust.

Theoretical: The DESI best-fit requires phantom dark energy ($w < -1$) at $z > 0.4$ in 99.9% of the posterior. Phantom dark energy requires ghost degrees of freedom with negative kinetic energy, leading to unbounded Hamiltonians and instantaneous vacuum decay. No stable field theory can produce DESI's w(z) trajectory.

The theoretical argument is decisive. Even if statistical and systematic concerns were fully addressed, the physics required by DESI's best-fit is pathological. The theoretical prior strongly favors $w = -1$.

We conclude that DESI has not detected evolving dark energy. The claimed signal is either a statistical/systematic artifact or would require physics that violates fundamental stability requirements. The cosmological constant remains the theoretically preferred—and observationally consistent—explanation for cosmic acceleration.

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Appendix A: MCMC Analysis Details

A.1 Data

We analyzed DESI MCMC chains (chain_1.txt through chain_4.txt) containing 61,168 total samples. All statistics are computed using chain weights to properly represent the posterior distribution.

A.2 Pivot Redshift Derivation

For the CPL parametrization $w(a) = w_0 + w_a(1-a)$, the variance of w at scale factor a is:

$$\sigma^2[w(a)] = \sigma^2_{w_0} + 2(1-a)\mathrm{Cov}(w_0, w_a) + (1-a)^2\sigma^2_{w_a}$$

Taking the derivative and setting to zero:

$$\frac{d\sigma^2}{da} = -2\mathrm{Cov}(w_0, w_a) - 2(1-a)\sigma^2_{w_a} = 0$$

Solving:

$$a_p = 1 + \frac{\mathrm{Cov}(w_0, w_a)}{\sigma^2_{w_a}}$$

With the DESI posterior values $\mathrm{Cov}(w_0,w_a) = -0.01154$ and $\sigma^2(w_a) = 0.04936$:

$$a_p = 1 + \frac{-0.01154}{0.04936} = 0.766$$

Corresponding to z_p = 1/a_p - 1 = 0.31.

A.3 Mahalanobis Distance

The squared Mahalanobis distance from the posterior mean to ΛCDM ($w_0 = -1$, $w_a = 0$) is:

$$D^2_M = \begin{pmatrix} -1-(-0.752) \\ 0-(-0.861) \end{pmatrix}^T \begin{pmatrix} 0.00328 & -0.01154 \\ -0.01154 & 0.04936 \end{pmatrix}^{-1} \begin{pmatrix} -0.248 \\ 0.861 \end{pmatrix} = 18.71$$

For $\chi^2(2)$, this gives $p = 8.67 \times 10^{-5}$, equivalent to 3.9σ.

Appendix B: The Ghost No-Go Theorem

B.1 Canonical Scalar Field

For a canonical scalar with Lagrangian $\mathcal{L} = ½(\partial\varphi)^2 - V(\varphi)$, the stress-energy tensor gives:

$$\rho = \frac{1}{2}\dot{\phi}^2 + V, \quad p = \frac{1}{2}\dot{\phi}^2 - V$$

Therefore:

$$\rho + p = \dot{\phi}^2 \geq 0$$

This is the null energy condition. Since $\rho > 0$ (assuming $V > 0$ or small enough kinetic energy), we have:

$$w = \frac{p}{\rho} = \frac{\dot{\phi}^2/2 - V}{\dot{\phi}^2/2 + V} \geq -1$$

with equality only when $\dot{\varphi} = 0$ (pure cosmological constant).

B.2 Phantom Field

To achieve $w < -1$ requires $\rho + p < 0$, which requires negative kinetic energy:

$$\mathcal{L}_{\text{phantom}} = -\frac{1}{2}(\partial\phi)^2 - V(\phi)$$

The Hamiltonian is:

$$H = \pi\dot{\phi} - \mathcal{L} = -\frac{1}{2}\dot{\phi}^2 + \frac{1}{2}(\nabla\phi)^2 + V$$

where $\pi = \partial\mathcal{L}/\partial\dot{\varphi} = -\dot{\varphi}$.

The kinetic contribution $-½\varphi^2$ is negative and unbounded. The Hamiltonian has no minimum—the vacuum is unstable.

B.3 Vacuum Decay Rate

In an interacting theory, a ghost can pair-produce with ordinary particles:

$$\text{vacuum} \rightarrow \text{ghost} + \text{particle} + \text{particle}$$

Energy is conserved because the ghost carries negative energy. The rate per unit volume, integrated over final-state phase space, diverges. The vacuum decays instantaneously.

This is not a technical issue that might be resolved with better understanding—it is a fundamental pathology that renders phantom field theory physically meaningless.

Appendix C: EFT Stability vs Background Inference

The analysis in Section IV establishes that the DESI CPL best-fit implies $w < -1$ at $z > 0.4$ for 99.9% of the posterior. We argued this constitutes "phantom" behavior requiring ghost degrees of freedom. Here we clarify the scope of this argument.

C.1 What Background Inference Does and Does Not Determine

Cosmological observations of $H(z)$, $D_M(z)$, and $D_H(z)$ constrain the background expansion history, from which an effective equation of state $w(z)$ can be inferred. However, this effective $w(z)$ is a background-level quantity only. It does not uniquely determine:

1. **The kinetic structure** of the underlying field theory
2. **Perturbation stability** (ghost-free, $c_s^2 > 0$, no gradient instabilities)
3. **Whether the theory is single-field, multi-field, or modified gravity**

C.2 Effective Phantom Without Fundamental Ghosts

Effective $w_{eff} < -1$ can arise without a fundamental ghost in specific constructions:

- **Interacting dark energy:** Energy exchange between DE and dark matter can make the inferred w_{eff} appear phantom even if the underlying field satisfies $w \geq -1$.
- **Multi-field models:** Certain configurations can produce transient phantom-like behavior while maintaining overall stability.
- **Modified gravity EFTs:** Some scalar-tensor theories produce phantom-like background evolution; stability depends on EFT coefficients (α_K, α_B, α_T, etc.), not $w(z)$ alone. The surviving class after GW170817 is DHOST Class Ia (Degenerate Higher-Order Scalar-Tensor, Class Ia degeneracy condition), which enforces $c_T = c$ via $\alpha_T = 0$, avoids Ostrogradsky ghosts via the degeneracy, and maintains positive scalar kinetic energy. DHOST Class Ia can produce effective $w_{eff} < -1$ at the background level through non-minimal curvature coupling without any phantom field. **Concrete realization:** The Selective Transient Field (STF) is a DHOST Class Ia theory in which the T^2 compact topology sources effective phantom behavior geometrically: Λ_{eff} grew toward its current value as the causal diamond was traversed, producing $w(z) < -1$ at all $z > 0$. At $z = 0$ the coupling rate vanishes exactly (third-order tangency at $\theta = \pi/2$), giving $w_0 = -1$ derived, not fitted. The STF $w(z)$ trajectory has no phantom crossing from above and disagrees with DESI's CPL shape — it is a distinct, falsifiable prediction. See STF Energy V0.3 §VIII and supporting derivation STF_Dark_Energy_wz_Derivation_V0_1.md.

C.3 Why the Theoretical Concern Remains

The constructions above are not generic escapes:

1. **Interacting DE** requires specific coupling structures and is constrained by CMB/LSS.
2. **Multi-field phantom** typically suffers gradient instabilities unless carefully tuned.
3. **Modified gravity** is severely constrained by GW170817 ($c_T = c$ to 10^{-15}), which eliminates large classes of Horndeski/beyond-Horndeski models. DHOST Class Ia survives this constraint by construction; other classes do not.

The point is not that phantom-like $w(z)$ is absolutely impossible in all frameworks, but that:

- For canonical single-field quintessence, it is impossible.

- For broader constructions, it requires non-trivial model-building that must be checked case-by-case for stability.
- The DESI CPL best-fit trajectory specifically — w crossing from above −1 at z ≈ 0.4, with $w_0 = -0.752$ today — does not match the prediction of any known stable model. The STF trajectory ($w_0 = -1$ exactly, no crossing) is stable and disagrees with DESI's shape. If DESI's actual w(z) shape is confirmed at high significance by future data, it would require a model that has not yet been constructed.

The theoretical prior therefore remains: observational claims of $w < -1$ should be treated with skepticism until a concrete, stable microphysical model matching the claimed w(z) shape is demonstrated. The existence of ghost-free effective phantom models (such as STF) confirms that $w < -1$ is not inherently pathological — but those models predict a trajectory that is incompatible with DESI's CPL best-fit.

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