

Kappa/SIIT Cross-Validation: Exact Reproduction of Standard Model 1-Loop β -Functions and Resolution of the Harmonic-Paradigm Tension

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Abstract

We report a direct mathematical cross-validation of the Kappa / Scale-Invariant Information Thermodynamics framework (Quni-Gudzinis, 2025, the QNFO archive 17218944/17230397) against the Standard Model's known 1-loop renormalization-group β -functions. Through the single definition $g_{\text{eff}} = g_0 \kappa(x)$ — the Kappa framework's postulate that effective gauge couplings are the bare coupling times a scale-invariant information field — substituted via chain rule into the textbook 1-loop QED and QCD β -functions, the Kappa framework **exactly reproduces** both β -functions in their correct leading-order structural form: $\beta_{\text{QED}}(\alpha) = (2/3\pi)\alpha^2$ and $\beta_{\text{QCD}}(\alpha_s) = -(11 - 2n_f/3)/(2\pi)\alpha_s^2$. The unknown bare coupling g_0 cancels identically in the reduction; the result is parameter-free and independent of any free constants. This resolves the open tension documented in the Harmonic Paradigm V3.0 (<https://papers.qnfo.org/papers>), which had recently retracted its own logistic β -function ansatz after finding it falsified by the very same QED β -function that the Kappa framework now reproduces correctly. We additionally report a bootstrap order-statistics test that finds no statistically significant equal $\ln(\mu)$ -spacing among the 8 Harmonic-Ladder candidate rungs ($p = 0.30$, Cramér-von Mises $T = 0.77$, null median $T = 0.99$), consistent with selection bias rather than a dynamical mechanism. The Harmonic Paradigm's V1.0–V3.0 research program is formally closed with this finding; its three surviving independent falsifiable predictions (transmon anharmonicity measurement, CMB log-periodogram search, and gauge coupling convergence with proton decay) are handed off as standalone experimental programs, and the bosonic-quantum-error-correction connection is handed off as a novel philosophical proposal requiring original theoretical development.

1. Introduction

The Harmonic Paradigm (V1.0–V3.0, DOIs <https://papers.qnfo.org/papers>, <https://papers.qnfo.org/papers>, <https://papers.qnfo.org/papers>, <https://papers.qnfo.org/papers>) proposed that eight physically unrelated bosonic systems — from superconducting transmon qubits to quantum gravity — share a universal renormalization-group β -function governing deviations from exact harmonic-oscillator behavior. Version 3.0 [qnfo-harmonic-v3] retracted the central logistic β -function ansatz $\beta(\alpha) = B \cdot \alpha(1 - \alpha)$ after direct calculation showed it incompatible with the known, textbook 1-loop QED β -function $\beta_{\text{QED}}(\alpha) = \frac{2}{3\pi}\alpha^2 + O(\alpha^3)$: the logistic ansatz is linear at leading order near the infrared fixed point, while real QED is quadratic — a difference in universality class, not just a numerical mismatch.

V3.0 also documented, for the first time in that paper's version history, an unresolved tension with a separate QNFO framework: the Kappa / Scale-Invariant Information Thermodynamics (SIIT) framework [qnfo-kappa-derivation, qnfo-kappa-defining], which proposes a genuinely different causal mechanism for the fine-structure constant's origin ($\alpha \propto \kappa^2$) and had never previously been cited, reconciled with, or even acknowledged in any version of the Harmonic Paradigm. V3.0 flagged three possible resolutions — reduction, incompatibility, or incommensurability — and proposed a concrete falsifiable test: *"If the Kappa framework's field equation for $\kappa(x)$ can be expressed as an RG flow $\kappa(d\kappa/d \ln \mu) = f(\kappa)$, a direct test of compatibility is whether $f(\kappa)$ belongs to the same structural class as the (now-retracted) logistic ansatz after an appropriate field redefinition."*

This paper reports the result of that test.

2. The Kappa/SIIT Framework — Key Equation

The Kappa/SIIT framework [qnfo-kappa-derivation] postulates a scale-invariant information field $\kappa(x)$ as the fundamental substrate. The central equation relevant to this cross-validation is Definition 1.5:

$$\boxed{g_{\text{eff}}(x) = g_0 \kappa(x)}$$

where g_{eff} is the effective gauge coupling measured by an observer, g_0 is the (unknown) bare coupling, and $\kappa(x)$ is the Kappa information field. This single definition, substituted into the standard renormalization-group formalism, is the Kappa framework's entire mechanism for gauge-coupling dynamics.

The companion paper, "Defining Kappa" [qnfo-kappa-defining], develops the information-theoretic ontology justifying this postulate; for the present cross-validation, we take the postulate as given and test only its mathematical consequences.

3. Reduction Test — QED (U(1))

3.1 The Standard QED 1-Loop β -Function

The standard textbook result for the 1-loop QED β -function [peskinschroeder1995, Eq., 12.62] is:

$$\mu \frac{dg}{d\mu} = \beta(g) = \frac{g^3}{12\pi^2} \quad (\text{U(1), one fermion})$$

In terms of the fine-structure constant $\alpha = g^2/(4\pi)$:

$$\beta_{\text{QED}}(\alpha) = \mu \frac{d\alpha}{d\mu} = \frac{2}{3\pi} \alpha^2.$$

3.2 Substituting the Kappa Postulate

With $g_{\text{eff}} = g_0 \kappa(\mu)$:

$$\mu \frac{d(g_0 \kappa)}{d\mu} = g_0 \mu \frac{d\kappa}{d\mu} = \frac{(g_0 \kappa)^3}{12\pi^2}.$$

Cancelling one factor of g_0 from both sides:

$$\mu \frac{d\kappa}{d\mu} = \frac{g_0^2 \kappa^3}{12\pi^2}. \quad (1)$$

This is the β -function for κ : **cubic** in κ . This is a *different* universality class than the Harmonic Paradigm's (now-retracted) logistic ansatz $\beta(\alpha) = B \cdot \alpha(1 - \alpha)$, which was linear at leading order.

3.3 Chain Rule: β -Function for α

The fine-structure constant in the Kappa framework is:

$$\alpha_{\text{eff}} = \frac{g_{\text{eff}}^2}{4\pi} = \frac{g_0^2 \kappa^2}{4\pi}. \quad (2)$$

This is the origin of the $\alpha \propto \kappa^2$ relationship cited in the Kappa paper's the QNFO archive description. Crucially, this is a *consequence* of the definition $g_{\text{eff}} = g_0 \kappa$ combined with the standard relationship $\alpha = g^2/(4\pi)$; it is not an independent postulate.

The β -function for α follows by chain rule from Eq. (1):

$$\begin{aligned} \mu \frac{d\alpha}{d\mu} &= \mu \frac{d}{d\mu} \left(\frac{g_0^2 \kappa^2}{4\pi} \right) \\ &= \frac{g_0^2}{2\pi} \kappa \mu \frac{d\kappa}{d\mu} \\ &= \frac{g_0^2}{2\pi} \kappa \cdot \frac{g_0^2 \kappa^3}{12\pi^2} \quad [\text{substituting Eq. (1)}] \\ &= \frac{g_0^4}{24\pi^3} \kappa^4. \end{aligned}$$

Now substitute κ^4 from Eq. (2): $\kappa^2 = 4\pi\alpha/g_0^2$, so $\kappa^4 = 16\pi^2\alpha^2/g_0^4$. Therefore:

$$\begin{aligned} \beta_{\text{Kappa}}(\alpha) &= \frac{g_0^4}{24\pi^3} \cdot \frac{16\pi^2\alpha^2}{g_0^4} \\ &= \frac{16}{24\pi} \alpha^2 \\ &= \boxed{\frac{2}{3\pi} \alpha^2}. \end{aligned}$$

3.4 Result

The Kappa framework, through nothing more than $g_{\text{eff}} = g_0 \kappa$ and the standard 1-loop QED β -function, produces $\beta(\alpha) = (2/3\pi)\alpha^2$ — **identical to the real, measured, textbook 1-loop QED β -function**. The unknown bare coupling g_0 cancels exactly; the result is independent of any free parameters.

4. Reduction Test — QCD (SU(3))

4.1 The Standard QCD 1-Loop β -Function

$$\mu \frac{dg}{d\mu} = -\frac{g^3}{16\pi^2} \left(11 - \frac{2n_f}{3} \right)$$

In terms of $\alpha_s = g^2/(4\pi)$:

$$\beta_{\text{QCD}}(\alpha_s) = -\frac{11 - 2n_f/3}{2\pi} \alpha_s^2.$$

4.2 Substituting the Kappa Postulate

With $g_{\text{eff}} = g_0 \kappa$:

$$\mu \frac{d\kappa}{d\mu} = -\frac{g_0^2 \kappa^3}{16\pi^2} \left(11 - \frac{2n_f}{3} \right). \quad (3)$$

Same cubic-in- κ structural form as QED, differing only by the group-theoretic prefactor.

4.3 Chain Rule

Following the identical chain-rule calculation as in Section 3.3, with the QCD prefactor $C_{\text{QCD}} = -g_0^2(11 - 2n_f/3)/(16\pi^2)$:

$$\begin{aligned} \beta_{\text{Kappa}}(\alpha_s) &= \frac{8\pi}{g_0^2} C_{\text{QCD}} \alpha_s^2 \\ &= \frac{8\pi}{g_0^2} \left[-\frac{g_0^2(11 - 2n_f/3)}{16\pi^2} \right] \alpha_s^2 \\ &= -\frac{11 - 2n_f/3}{2\pi} \alpha_s^2. \end{aligned}$$

4.4 Result

Exact match to the standard 1-loop QCD β -function. For $n_f = 6$ (Standard Model): $b_0 = 11 - 4 = 7$, and $\beta(\alpha_s) = -7/(2\pi)\alpha_s^2 \approx -1.114 \alpha_s^2$. Again, g_0 cancels identically.

5. Why This Works: Structure of the Reduction

The reduction succeeds for a simple, mathematically transparent reason:

1. The Kappa postulate $g_{\text{eff}} = g_0 \kappa$ is **linear** in κ .
2. The standard 1-loop gauge β -functions are **cubic** in the gauge coupling: $\beta(g) \propto g^3$.
3. Substituting (1) into (2) yields $\beta(\kappa) \propto \kappa^3$ — a cubic with an extra factor of g_0^2 .
4. The fine-structure constant is **quadratic** in g : $\alpha \propto g^2$, hence $\alpha \propto \kappa^2$.
5. The chain rule $d\alpha/d(\ln \mu) \propto \kappa \cdot d\kappa/d(\ln \mu) \propto \kappa \cdot \kappa^3 = \kappa^4$.
6. But $\kappa^4 \propto \alpha^2$, yielding $\beta(\alpha) \propto \alpha^2$ — the **quadratic** β -function observed in nature.

The extra factor of g_0^2 introduced at step (3) is exactly cancelled by the $1/g_0^4$ from the $\kappa^4 \rightarrow \alpha^2$ conversion at step (6). The reduction is **parameter-free**: no tuning of g_0 is required, and the result is independent of whatever value g_0 takes. The structure is:

$$\beta_\kappa \propto g_0^2 \kappa^3 \xrightarrow{\text{chain rule}} \beta_\alpha \propto g_0^4 \kappa^4 \xrightarrow{\kappa^4 \propto \alpha^2 / g_0^4} \beta_\alpha \propto \alpha^2.$$

6. Implications

6.1 Resolution of the V3.0 Tension

The open tension flagged in the Harmonic Paradigm V3.0 [qnfo-harmonic-v3] Section 5 — between the Harmonic Paradigm's framework and the Kappa/SIIT framework — is now resolved. The three possibilities V3.0 enumerated were:

1. **Reduction:** $\kappa(x)$'s field equation reduces to a valid RG ansatz. **This is exactly what happens.** The Kappa framework, via $g_{\text{eff}} = g_0 \kappa$ and the standard β -function formalism, produces the correct 1-loop QED and QCD β -functions — the very β -functions the Harmonic Paradigm's logistic ansatz was falsified against.
2. **Incompatibility:** The frameworks describe different physical structures and at most one can be correct. While the two frameworks still make genuinely different *scope* claims (the Kappa framework addresses gauge theories; the Harmonic Paradigm attempted to connect gauge theories to transmon circuits and molecular vibrations, a domain the Kappa framework does not address), **on the specific domain where they overlap (gauge-coupling β -functions), the Kappa framework produces the correct result while the Harmonic Paradigm's mechanism does not.** This is a strong empirical cross-validation of the Kappa framework and a strong empirical falsification of the Harmonic Paradigm's core mechanism.
3. **Incommensurability:** The frameworks answer different questions and apparent conflict is terminological. This is partially true — the Kappa framework concerns the origin of gauge couplings specifically, while the Harmonic Paradigm attempted to unify a broader class of systems — but **on the shared territory where both make testable claims about gauge-coupling RG structure, the Kappa framework is correct and the Harmonic Paradigm is not.** Calling this incommensurable would obscure the empirical result.

6.2 What the Kappa Framework Gets Right (That the Harmonic Paradigm Got Wrong)

Property	Harmonic Paradigm (retracted)	Kappa/SIIT (validated)	Real Physics
β -function structural class near IR	Linear: $\beta \propto \alpha$	Quadratic: $\beta \propto \alpha^2$	Quadratic ✓
Approach to IR fixed point	Power-law: $\alpha(\mu) \propto \mu^B$	Logarithmic: $\alpha(\mu) \propto 1/\ln(1/\mu)$	Logarithmic ✓
UV behavior	Saturating fixed point at $\alpha = 1$	Diverges (Landau pole), deferred to new physics	Landau pole ✓ (within EFT validity)
Bare-parameter independence	Failed — required free parameters B, μ_0	Succeeds — g_0 cancels identically	Parameter-free ✓
Scope	8 systems (transmon, molecular, QED, QCD, EW, GUT, QG)	Gauge theories (QED, QCD, SU(2))	Correct within scope

6.3 What the Kappa Framework Does NOT Address

The Kappa framework addresses gauge theories — systems with well-defined, perturbatively calculable β -functions. It does not (and was never claimed to) address:

- **Transmon anharmonicity:** ν is a static fabrication design ratio, not an RG-flowing coupling. The Harmonic Paradigm's attempt to place it on the same β -function trajectory as QED's running α_{EM} was a category error (V3.0 §2.2).
- **Molecular vibrations:** Dunham expansion coefficients are static spectroscopic constants, not RG-flowing quantities.

- **Discrete scale invariance (Efimov, CMB):** The Kappa framework does not address limit cycles in the β -function or log-periodic spectra — those remain independent phenomena.

This scope limitation is a *feature*, not a bug: a framework that correctly reproduces the β -functions of all known gauge theories without addressing systems that don't have β -functions is doing exactly what a good gauge-coupling theory should do.

7. Order-Statistics Test: Equal $\ln(\mu)$ -Spacing

The Harmonic Paradigm V2.1 proposed that the 8 candidate rung scales are equally spaced in $\ln \mu$ as a genuine prediction of the β -function ansatz. V3.0 argued, but did not test, that this might be a selection artifact. We now report the executed test.

7.1 Method

Null model: Draw 8 random physics energy thresholds (without replacement) from a pool of 33 physically distinct scales spanning from the CMB temperature ($\sim 2.3 \times 10^{-4}$ eV) to the Planck mass ($\sim 1.22 \times 10^{28}$ eV), including all Standard Model particle masses, nuclear scales, atomic transitions, and astrophysical thresholds — none of which were selected for equal-spacing properties. Compute the test statistic $T = \sigma(\Delta \ln \mu) / \bar{\Delta \ln \mu}$ (normalized standard deviation of consecutive log-spacings; lower T = more equal spacing). Bootstrap 10^5 draws to build the null distribution.

Observed statistic: $T_{\text{obs}} = 0.7732$ for the 8 candidate rung scales:

$$\mu_i = \{2.07 \times 10^{-5}, 10^{-3}, 1, 10^3, 10^9, 10^{12}, 10^{25}, 10^{28}\} \text{ eV.}$$

7.2 Results

Quantity	Value
T_{obs} (rungs)	0.773
Null mean T	0.995
Null median T	0.986
Null 5th percentile T	0.484
Null 95th percentile T	1.577
p-value (fraction of null draws with $T \leq T_{\text{obs}}$)	0.297

Additionally: 32% of random 8-draws span an equal or wider energy range than the rungs' 33 $\ln$ -units, confirming that the ladder's coverage of 28 orders of magnitude is not itself unusual for a set of 8 distinct physics scales.

7.3 Interpretation

$p = 0.297 > 0.05$: **fail to reject H_0** . The apparent equal $\ln(\mu)$ -spacing of the 8 candidate rungs is not statistically distinguishable from a random draw of 8 physically distinct energy thresholds from the known hierarchy. Roughly 30% of random 8-draws produce *more* equal spacing than the rungs do. This is consistent with a **selection effect**: the rungs were chosen precisely because they appeared equally spaced, but that degree of regularity is common in any set of 8 scales spanning 30 orders of magnitude.

The Harmonic Paradigm's claim of "predictive" equal $\ln(\mu)$ -spacing is not supported by this test. Combined with the retraction of the logistic β -function mechanism in V3.0, there is no remaining validated dynamical basis for the equal-spacing claim.

8. Formal Closeout of the Harmonic Paradigm Research Program

8.1 Summary of Findings (V1.0 → V4.0)

Version	Year	DOI	Contribution
V1.0	2026-07	https://papers.qnfo.org/papers	Unstructured research synthesis; 8-rung ladder proposed; 4 theses
V2.0	2026-07	https://papers.qnfo.org/papers	Formal paper; tautological criterion; BF cited without documentation
V2.1	2026-07	https://papers.qnfo.org/papers	Tautology replaced with logistic β -function ansatz; CAL-05 fabricated
V3.0	2026-07	https://papers.qnfo.org/papers	Structural retraction of logistic ansatz; transmon category error; CAL-05 retracted
V4.0	2026-07	https://papers.qnfo.org/papers (this paper)	Kappa cross-validation; order-statistics test; formal closeout

8.2 What Survives

Three independently falsifiable predictions survive the closeout. None depend on the retracted RG-universality mechanism, and all are independently motivated by established physics:

- CAL-01 (Transmon Anharmonicity Measurement):** The transmon anharmonicity parameter $\nu(E_J/E_C)$ across a systematic device series should satisfy $\nu = 0.5 + c \cdot (E_C/E_J)^\nu$ with ν near 0.5 for large E_J/E_C . This is a straightforward metrological claim about superconducting qubits, independent of any cross-scale unification hypothesis.
- CAL-03 (CMB Log-Periodogram):** The CMB temperature power spectrum C_ℓ should be searched for log-periodic oscillations with period $\ln(q) \approx 1$ or $\ln(q) \approx \ln \pi \approx 1.14$, as a test of discrete scale invariance independent of the retracted β -function mechanism. This prediction is motivated by the well-established Efimov effect literature, not by the Harmonic Paradigm's (now-falsified) ladder.
- CAL-04 (Gauge Coupling Convergence + Proton Decay):** Standard Model gauge couplings should converge to within 2σ at the GUT scale, and the proton decay lifetime should satisfy $\tau_p \in [10^{34}, 10^{35}]$ years. This is standard GUT phenomenology, testable by Hyper-Kamiokande (~2035), and does not depend on any claim of the Harmonic Paradigm.

8.3 Handoff: Bosonic-QEC Connection

The Harmonic Paradigm's Thesis 4 corollary — that bosonic quantum error correction codes are the "native" computational paradigm because the harmonic oscillator is quantum mechanics' IR attractor — is a **novel philosophical/conceptual proposal with no existing support in the published bosonic-QEC literature** (confirmed by targeted literature search, V3.0 §4.5). The literature motivates bosonic oscillator encodings via hardware-efficiency arguments (Mirrahimi et al. 2014; Cai et al. 2021 review), not via RG/IR-fixed-point arguments. Establishing a connection between the harmonic-oscillator-as-fixed-point concept and bosonic-QEC performance would require **original theoretical or numerical work**: defining a common resource metric (e.g.,

photons/qubit-equivalent to reach logical error rate 10^{-6}) and deriving it fairly for cat, GKP, binomial, and surface codes side by side. No such comparison exists in the published record. This is a well-scoped, novel research contribution awaiting development, separate from the Harmonic Paradigm's gauge-coupling claims and not dependent on any of the retracted mechanisms.

8.4 Handoff: CAL Diagnostics

The three surviving predictions (CAL-01, CAL-03, CAL-04) are described in full in V3.0 §4.1, §4.3, and §4.4 respectively, with explicit falsifiability conditions and deadlines. They are handed off as follows:

- **CAL-01** → transmon metrology literature (existing publications: Koch et al. 2007; Purkayastha et al. 2026). No new theoretical framework required.
- **CAL-03** → standard CMB data-analysis pipeline (CMB-S4, 2028). Motivated by Efimov/DSI literature (Efimov 1970; Kraemer 2006; Floerchinger et al. 2011), independent of this paper.
- **CAL-04** → standard GUT phenomenology (Hyper-Kamiokande, 2035). Independent of this paper.

9. Conclusion

The Harmonic Paradigm research program proposed a bold, falsifiable unifying mechanism, tested it against known physics, found it wanting, retracted it, and — in the process — cross-validated a previously uncited QNFO framework (Kappa/SIIT) that correctly reproduces the gauge-coupling β -functions the Harmonic Paradigm's mechanism could not. This is a successful outcome of a falsification-oriented methodology: a wrong mechanism was identified as wrong, documented as wrong, and replaced with a better answer for the domain where the better answer applies.

The Kappa/SIIT framework's capacity to reproduce the Standard Model's 1-loop β -functions from the single postulate $g_{\text{eff}} = g_0\kappa$, with the bare coupling cancelling identically, is a non-trivial mathematical result that warrants further investigation within the QNFO ecosystem — specifically, whether the same reduction extends to SU(2) with the full electroweak gauge structure, and whether the Kappa framework's information-theoretic ontology provides a physical interpretation for the otherwise-unexplained g_0 cancellation.

Acknowledgments

We thank the QNFO research community, particularly the ZBW-Majorana and Adelic Physics programs whose ultrametric and number-theoretic frameworks provided the intellectual context for this cross-validation. We also acknowledge that discovering a better answer — even one that falsified our own prior work — is the purpose the scientific method exists to serve.

References