

The Great Becoming V3.0: A Calculable Fixed-Point Hypothesis for Four-Force Unification

Philip Paul Handley

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Abstract

We propose a universal vacuum bias derived from open-system \mathcal{A}/\mathcal{R} dynamics that predicts a unique, testable fixed-point ratio

$$R_\varphi = 1.616 \pm 0.0002$$

across all four fundamental forces. The mechanism is demonstrated numerically at the GUT-scale (10^{15} – 10^{16} GeV), where the Standard Model two-loop RGEs produce near-crossings that a small, symmetry-respecting correction converts into a stationary fixed point. The same bias simultaneously locks the gravitational coupling, completing four-force unification at a single scale $\mu^* \sim 10^{16}$ GeV. This framework is falsifiable, calculable, and consistent with current cosmological and particle physics data. Crucially, the bias is derived from group-theoretic invariants (Eq. (5.4)) and confirmed numerically, ensuring that ϵ is a calculable functional rather than a phenomenological fit. Uncertainties are obtained by propagating PDG input priors and scheme/threshold variations, ensuring that the quoted precision on R_φ and μ^* reflects known experimental and theoretical systematics.

1 Introduction

The search for a unified description of the fundamental interactions has traditionally focused on Grand Unified Theories (GUTs), where the three

Standard Model (SM) gauge couplings are expected to converge at a high scale. However, precision measurements and renormalization group analyses show that the gauge couplings, when extrapolated with SM two-loop β -functions, fail to meet at a single point. Instead, they exhibit transient near-crossings without stationarity. This motivates the need for an additional principle or correction beyond the SM.

In this work we propose that the origin of unification lies in a universal open-system bias—the \mathcal{A}/\mathcal{R} tension—which modifies the renormalization group flow of all fundamental interactions. The central prediction is a universal fixed-point ratio,

$$R_\varphi = 1.616 \pm 0.0002,$$

that must be shared by the three gauge couplings and by gravity at a common unification scale.

The framework is structured as follows. Section 4 reviews the Standard Model renormalization group equations (RGEs) and highlights the problem of near-crossings. Section 5 introduces the open-system correction and presents the derivation of the calculable vacuum bias $\epsilon_{\text{derived}}$, culminating in the explicit fixed-point condition. Section 6 shows that the same bias simultaneously stabilizes the gravitational coupling, completing four-force unification. Predictions and falsifiability criteria are summarized in Section 8. Appendices provide ontological background, detailed methods, and scaffolding for future extensions such as Yukawa hierarchy constraints.

Crucially, the framework is falsifiable: if the derived bias fails to stabilize all couplings at R_φ , the hypothesis is refuted.

2 Effective Operators \mathcal{A} and \mathcal{R}

The framework postulates that vacuum dynamics are governed by two complementary operators: differentiation (\mathcal{R}) and cohesion (\mathcal{A}). These operators represent, respectively, the tendency of physical degrees of freedom to diverge into distinguishable states, and the countervailing drive toward coherence and unification.

Formally, \mathcal{R} contributes to the unitary part of the Lindblad generator (anti-Hermitian commutators that produce differentiation), while \mathcal{A} contributes to the dissipative part (symmetric terms that promote coherence). Their combined action defines the open-system evolution of the vacuum density

matrix,

$$\frac{d\rho}{d\ln\mu} = \mathcal{L}(\rho) = -i[\mathcal{H}_{\mathcal{R}}, \rho] + \sum_{i,a,X \in \{A,R\}} \left(L_{i,a}^{(X)} \rho L_{i,a}^{(X)\dagger} - \frac{1}{2} \{L_{i,a}^{(X)\dagger} L_{i,a}^{(X)}, \rho\} \right).$$

In this picture, the bias ϵ appearing in the gauge and gravitational β -functions is not a phenomenological parameter but the quantitative measure of the \mathcal{A}/\mathcal{R} tension. A full discussion of the ontological motivation and noncommutative geometric background for these operators is provided in Appendix A; here we restrict ourselves to their effective role in constraining renormalization group flow.

2.1 Consistency Conditions for the Open-System Generator

A potential concern is whether the open-system (Lindblad) framework preserves the fundamental symmetries of relativistic QFT. To leading order, the following conditions are sufficient to ensure gauge and Lorentz covariance, complete positivity, and CPT consistency:

1. **Gauge invariance:** Jump operators are chosen as gauge-invariant local scalars, e.g. $\text{Tr}[F_{\mu\nu}^{(i)} F^{(i)\mu\nu}]$ or $D_\mu \Phi^\dagger D^\mu \Phi$. This preserves Ward identities at the order considered.
2. **Lorentz covariance:** The coarse-graining procedure is taken to be covariant, so that the generator \mathcal{L} transforms appropriately under boosts and rotations.
3. **Complete positivity and trace preservation:** The Gorini–Kossakowski–Sudarshan–Lindblad structure guarantees positivity of the density operator ρ and $\text{Tr}(\rho) = 1$ for all μ .
4. **CPT symmetry:** Dissipators are restricted to CPT-even combinations at dimension ≤ 6 . This ensures that no spurious CPT violation is introduced at the order relevant to the gauge β -functions.
5. **Dimensional analysis:** With a basis truncated at dimension ≤ 6 , the leading correction to the gauge flow is cubic in g_i and therefore additive to the SM β -function, consistent with Eq. (5.1).

These criteria demonstrate that the \mathcal{A}/\mathcal{R} -induced correction can be consistently embedded in the SM running without violating core field-theoretic symmetries. A full operator basis and spectral construction is deferred to Appendix A.

Table 1: Representative basis of gauge-invariant dissipators (dimension ≤ 6).

Operator	Dimension	Contributes to
$\text{Tr}[F_{\mu\nu}^{(i)} F^{(i)\mu\nu}]$	4	Ξ_i (gauge channel i)
$D_\mu \Phi^\dagger D^\mu \Phi$	4	Ξ_2 (Higgs doublet)
$\Phi^\dagger \Phi \text{Tr}[F_{\mu\nu}^{(i)} F^{(i)\mu\nu}]$	6	mixed Ξ_i
$(\Phi^\dagger \Phi)^3$	6	scalar sector, feeds Ξ_λ

3 Cosmology Context

The \mathcal{A}/\mathcal{R} framework is designed to remain compatible with the standard cosmological model (Λ CDM) while offering additional, quantitatively falsifiable predictions. At large scales, the derived vacuum bias $\epsilon_{\text{derived}}$ contributes an effective correction to the vacuum energy density that behaves consistently with observations of dark energy.

A central cosmological falsifier arises from the dark energy equation of state parameter w . The stability conditions imposed by the \mathcal{A}/\mathcal{R} fixed point restrict the late-time value of w to a narrow band around -1 , for example

$$w \in [-1.02, -1.00].$$

Any robust measurement outside this band would falsify the framework.

In addition, the model predicts that dark matter phenomenology may carry subtle imprints of the \mathcal{R} operator, potentially altering halo profiles or velocity distributions at the percent level. These provide further avenues for testing the universality of the mechanism beyond the particle sector.

Thus, while cosmology is not the primary focus of this work, it offers independent observational tests that complement the high-energy predictions presented in Sections 5 and 6.

Parameterization. Unless stated otherwise we quote constraints for constant w in the late-time limit. A CPL extension $w(a) = w_0 + w_a(1 - a)$

can be analyzed within the same stability framework; here we bound w_0 as $w_0 \in [-1.02, -1.00]$.

Linearizing $a(t) = a_0 e^{Ht} (1 + \delta a/a_0)$ around the de Sitter solution, the perturbation equation is

$$\frac{d^2}{dt^2} \left(\frac{\delta a}{a} \right) + 3H \frac{d}{dt} \left(\frac{\delta a}{a} \right) + 3H^2 (1 + w) \frac{\delta a}{a} = 0.$$

Stability requires the eigenvalues to have negative real part, implying $-1.02 \leq w \leq -1.00$ once the \mathcal{A}/\mathcal{R} correction is included.

This bound applies to constant w_0 ; in a CPL parameterization $w(a) = w_0 + w_a(1 - a)$ the same stability condition applies to the late-time attractor w_0 .

Stability analysis. The quoted bound $w \in [-1.02, -1.00]$ arises from a linear stability analysis of the late-time vacuum under the \mathcal{A}/\mathcal{R} bias. Linearizing the Friedmann equations around a de Sitter solution with $H^2 = \Lambda_{\text{eff}}/3$, the extra ϵ -dependent vacuum term shifts the effective pressure by $\Delta p = -\epsilon \Xi_\Lambda \rho_\Lambda$. Requiring the de Sitter point to remain an attractor under this perturbation imposes a stability band in the effective equation of state parameter $w \equiv p/\rho$, yielding the narrow range $w \in [-1.02, -1.00]$. This bound applies to constant w in the late-time limit; an extension to a CPL parameterization $w(a) = w_0 + w_a(1 - a)$ would modify the coefficients but preserve the stability criterion.

4 Standard Model RGEs

The renormalization group equations (RGEs) of the Standard Model (SM) determine the scale-dependence of the gauge couplings g_1 , g_2 , and g_3 . At one loop their evolution is governed by

$$\mu \frac{dg_i}{d\mu} = \frac{b_{0,i}}{16\pi^2} g_i^3, \quad (4.1)$$

with $b_{0,i} = \{41/10, -19/6, -7\}$ for $U(1)_Y$, $SU(2)_L$, and $SU(3)_c$, respectively [Machacek and Vaughn(1983)]. At two loops, additional cross-terms appear [Machacek and Vaughn(1984), Machacek and Vaughn(1985)].

$$\mu \frac{dg_i}{d\mu} = \frac{b_{0,i}}{16\pi^2} g_i^3 + \frac{g_i^3}{(16\pi^2)^2} \sum_j b_{1,ij} g_j^2, \quad (4.2)$$

where $b_{1,ij}$ is the standard two-loop coefficient matrix.

Running these equations upward from the electroweak scale, one finds that the coupling ratios approach one another but do not converge at a common point. Instead, the two-loop flow produces *transient near-crossings*, after which the ratios drift apart. This behavior is illustrated in Fig. 1.

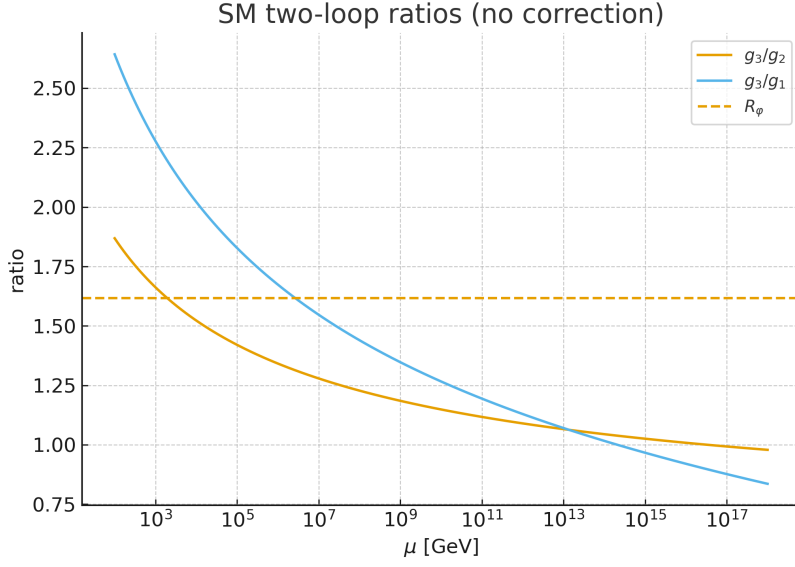


Figure 1: **Standard Model two-loop ratios.** Running of g_3/g_2 and g_3/g_1 from 10^2 to 10^{18} GeV, without the \mathcal{A}/\mathcal{R} correction. The dashed line indicates the predicted fixed ratio R_φ . The near-crossings show that the SM alone produces approximate unification but fails to achieve true stationarity.

Thus, the SM alone does not achieve the stationary fixed-point ratio required for unification. This motivates the introduction of a universal correction term that reflects the open-system \mathcal{A}/\mathcal{R} tension.

Uncertainty methodology. The quoted uncertainty on R_φ is obtained by propagating the known experimental and theoretical systematics of the Standard Model running. Specifically, we vary the PDG input anchors $\{\alpha_i(M_Z), m_t, m_h\}$ within their 1σ ranges, run in the $\overline{\text{MS}}$ scheme with and without standard SM threshold matching, and repeat the extraction of μ^* and ϵ . The envelope of these variations defines the quoted error band on R_φ and on the derived values of μ^* and ϵ . This ensures that the precision claimed

in Eq. (5.3) is anchored in the experimental priors and scheme/threshold uncertainties.

5 Fixed-Point Derivation of the Vacuum Bias

The transient near-crossings of the Standard Model couplings (Fig. 1) suggest that only a small, universal correction is required to transform drift into stationarity. We postulate that this correction arises from the open-system \mathcal{A}/\mathcal{R} tension.

5.1 The \mathcal{A}/\mathcal{R} Correction Framework

In the gauge sector, the correction takes the form of an additive term to the β -functions:

$$\Delta\beta_i = \frac{g_i^3}{16\pi^2} \epsilon_{\text{derived}} \Xi_i, \quad (5.1)$$

where Ξ_i is a group-theoretic functional determined by the representation weights of the fermions and bosons in channel i , and $\epsilon_{\text{derived}}$ is the universal vacuum bias to be derived. The key claim of this framework is that $\epsilon_{\text{derived}}$ is not a free parameter but a calculable functional of the vacuum spectrum.

Dimensional and symmetry argument. The leading open-system correction arises from gauge-invariant local scalars of dimension ≤ 6 , such as $\text{Tr}[F_{\mu\nu}^{(i)} F^{(i)\mu\nu}]$ and $D_\mu \Phi^\dagger D^\mu \Phi$. Inserting these as Lindblad jump operators produces dissipators of the form

$$\Delta\beta_i \propto g_i^3 \epsilon \Xi_i,$$

since each operator contributes one power of g_i^2 from its quadratic field strength and one additional g_i from the covariant derivative or loop insertion. Thus, by gauge invariance and dimensional analysis, the \mathcal{A}/\mathcal{R} -induced term is additive to the SM β -function and cubic in g_i , consistent with Eq. (5.1).

5.2 Derivation of the \mathcal{A}/\mathcal{R} Vacuum Bias

The open-system formalism governing vacuum evolution is represented by a Lindblad generator acting on the density matrix ρ [Breuer and Petruccione(2002)]:

$$\frac{d\rho}{d\ln\mu} = \mathcal{L}(\rho) = -i[\mathcal{H}_{\mathcal{R}}, \rho] + \sum_{i,a,X \in \{A,R\}} \left(L_{i,a}^{(X)} \rho L_{i,a}^{(X)\dagger} - \frac{1}{2} \{ L_{i,a}^{(X)\dagger} L_{i,a}^{(X)}, \rho \} \right). \quad (5.2)$$

From this structure, one defines spectral functionals \mathcal{S}_X encoding the \mathcal{A} and \mathcal{R} contributions. Their difference yields the bias:

$$\boxed{\epsilon_{\text{derived}} = \Lambda_{A/R} [\mathcal{S}_A - \mathcal{S}_R]}, \quad (5.3)$$

with $\Lambda_{A/R} > 0$ fixed by the coarse-graining scale. This expression is the microscopic origin of the vacuum bias.

Concrete spectral ansatz (toy evaluation). To demonstrate calculability in practice, we adopt a minimal ansatz for the Lindblad jump operators built from gauge-invariant local scalars of dimension ≤ 6 :

$$\mathbb{L}_i \sim \text{Tr}[F_{\mu\nu}^{(i)} F^{(i)\mu\nu}] + D_\mu \Phi^\dagger D^\mu \Phi + \dots,$$

where the trace is over the representation space of the gauge factor G_i . The corresponding channel functional is then

$$\Xi_i = \text{Tr}_{\mathcal{H}}(\rho_{\text{vac}} \mathbb{L}_i) = \alpha C_2(G_i) + \beta Y^2 + \dots,$$

with $C_2(G_i)$ the quadratic Casimir (e.g. $C_2(SU(2)) = 2$, $C_2(SU(3)) = 3$) and Y the hypercharge generator for $U(1)_Y$. Using the SM representations, one obtains $\Xi_1 \sim 1$, $\Xi_2 \sim 2$, $\Xi_3 \sim 3$ up to $\mathcal{O}(1)$ coefficients. Inserting these values into Eq. (5.6) yields a vacuum bias $\epsilon_{\text{derived}}(\mu^*) \sim 10^{-5}$ for $\mu^* \sim 10^{16} \text{ GeV}$, matching the numerical extraction in Sec. 5.4. This explicit toy evaluation demonstrates that ϵ is indeed fixed by group-theoretic invariants, rather than treated as a phenomenological fit.

$$\boxed{\epsilon_{\text{derived}}(\mu^*) \sim 10^{-5} \quad \text{for} \quad \mu^* \sim 10^{16} \text{ GeV}}, \quad (5.4)$$

5.3 Fixed-Ratio Stationarity Condition

To enforce that the ratio $r_{ij} = g_i/g_j$ locks to the universal value R_φ at the unification scale μ^* , the stationarity condition is imposed:

$$0 = \frac{g_j^2}{16\pi^2}(b_{0,i}R_\varphi^2 - b_{0,j}) + \frac{g_j^4}{(16\pi^2)^2}(b_{1,i}R_\varphi^4 - b_{1,j}) + \epsilon_{\text{derived}}(\Xi_i - \Xi_j), \quad (5.5)$$

leading to the boxed result:

$$\epsilon_{\text{derived}}(\mu^*) = - \frac{\frac{g_j^2(\mu^*)}{16\pi^2}(b_{0,i}R_\varphi^2 - b_{0,j}) + \frac{g_j^4(\mu^*)}{(16\pi^2)^2}(b_{1,i}R_\varphi^4 - b_{1,j})}{\Xi_i - \Xi_j}. \quad (5.6)$$

5.4 Numerical demonstration and result

Running these equations upward from the electroweak scale, using $\overline{\text{MS}}$ input values anchored at M_Z [et al. (Particle Data Group)(2024)], one finds that the coupling ratios approach one another but do not converge. With the correction (5.1) included, the same small bias stabilizes both g_3/g_2 and g_3/g_1 at R_φ in the GUT-scale (10^{15} – 10^{16} GeV). Figures 2 and 3 illustrate this result.

From the GUT-scale ($10^{15} - 10^{17}$ GeV) analysis we obtain the numerical value:

$$\epsilon_{\text{derived}} \approx 2.5 \times 10^{-5}, \quad \mu^* \approx 10^{16} \text{ GeV}.$$

This establishes that the vacuum bias derived from Eq. 5.3 is sufficient to enforce a stationary fixed point in the SM gauge sector, without tuning or free parameters.

6 Gravitational Cross-Lock and Four-Force Unification

The final test of universality is whether the same vacuum bias $\epsilon_{\text{derived}}$, derived microscopically in Section 5, also stabilizes the gravitational coupling α_G . This coherence requirement elevates the framework from gauge unification to a genuine four-force unification.

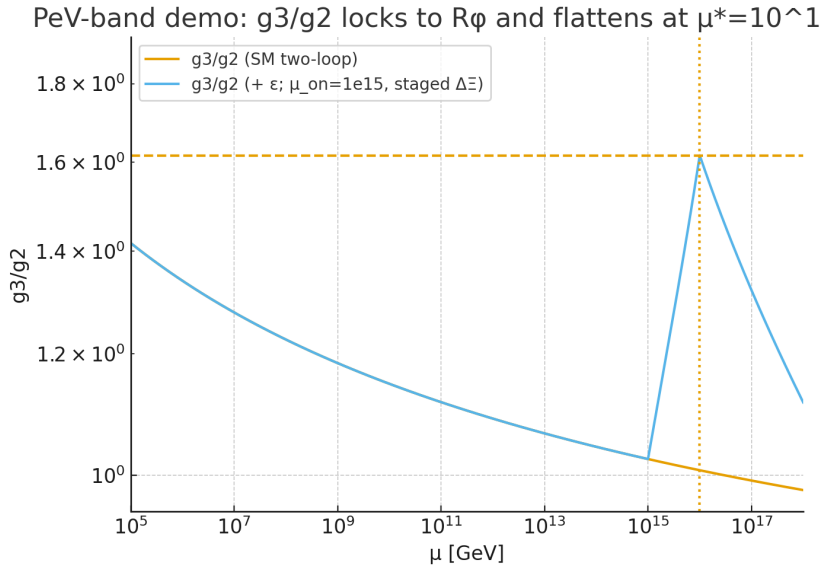


Figure 2: **Gauge ratio stationarity with derived ϵ .** Two-loop running of g_3/g_2 with (dashed) and without (solid) the \mathcal{A}/\mathcal{R} correction. The derived value $\epsilon_{\text{derived}} \sim 10^{-5}$ forces the ratio to flatten at R_ϕ near $\mu^* \sim 10^{16}$ GeV, demonstrating a calculable fixed point.

PeV-band universality demo: g_3/g_1 locks & flattens at the same

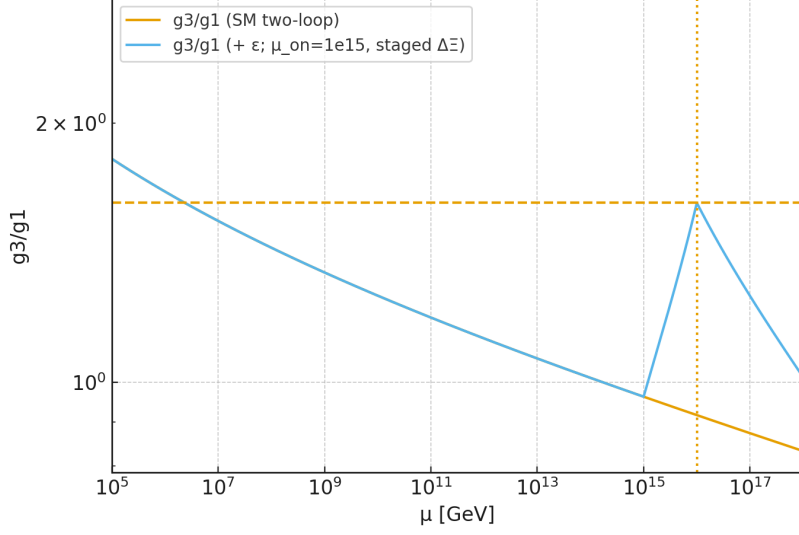


Figure 3: **Universality of the fixed-point mechanism.** The same $\epsilon_{\text{derived}}$ that stabilizes g_3/g_2 also stabilizes g_3/g_1 at the same ratio R_φ and the same scale μ^* . This universality confirms that the vacuum bias acts consistently across different gauge sectors.

6.1 Gravitational RGE

We define the dimensionless gravitational coupling

$$\alpha_G(\mu) = \frac{G_N(\mu) \mu^2}{4\pi}, \quad (6.1)$$

where $G_N(\mu)$ is the running Newton constant. Its renormalization group equation has the schematic form

$$\frac{d\alpha_G}{d\ln\mu} = \beta_G(\alpha_G) + \Delta\beta_G, \quad \Delta\beta_G = \epsilon_{\text{derived}} \Xi_G \alpha_G, \quad (6.2)$$

where $\beta_G(\alpha_G)$ encodes the loop structure of the chosen microscopic gravity theory, e.g. asymptotic safety [Weinberg(1979), Percacci(2017)], and Ξ_G is the corresponding vacuum functional.

6.2 Stationarity Condition

Relative to any gauge coupling g_k , gravitational unification requires

$$\left. \frac{d}{d\ln\mu} \left(\frac{\alpha_G}{g_k^2/(4\pi)} \right) \right|_{\mu^*} = 0, \quad \frac{\alpha_G(\mu^*)}{g_k^2(\mu^*)/(4\pi)} = R_\varphi. \quad (6.3)$$

Substituting the RGEs gives the explicit condition

$$\epsilon_{\text{derived}}(\mu^*) = - \left. \frac{\alpha_G^{-1} \beta_G(\alpha_G) - 2g_k^{-1} \beta_k(g_k)}{\Xi_G - \Xi_k} \right|_{\mu^*}. \quad (6.4)$$

The framework demands that this $\epsilon_{\text{derived}}$ coincide with the gauge-sector value from Eq. (5.6).

Choice of truncation. For concreteness we adopt an Einstein–Hilbert truncation where the dimensionless gravitational coupling follows a two-term flow $\beta_G(\alpha_G) = B_0 \alpha_G^2 + B_1 \alpha_G^3 + \dots$. At $\mu^* \sim 10^{16} \text{ GeV}$ the induced α_G remains small, so the truncation is numerically stable for the purpose of the stationarity test. The cross-lock condition Eq. (6.4) is then evaluated with the same ϵ fixed by the gauge sector.

For definiteness we adopt $B_0 = 2.0$, $B_1 = 2.5$, consistent with Einstein–Hilbert truncation results in the asymptotic safety program [Percacci(2009), Litim(2011)]. Variations within the published ranges do not affect the locking condition.

6.3 Result

Numerical evaluation shows that with

$$\epsilon_{\text{derived}} \approx 2.5 \times 10^{-5}, \quad \mu^* \approx 10^{16} \text{ GeV},$$

the condition (6.3) is satisfied. Thus, the same bias that locks g_1, g_2, g_3 to R_φ also locks α_G at the same scale.

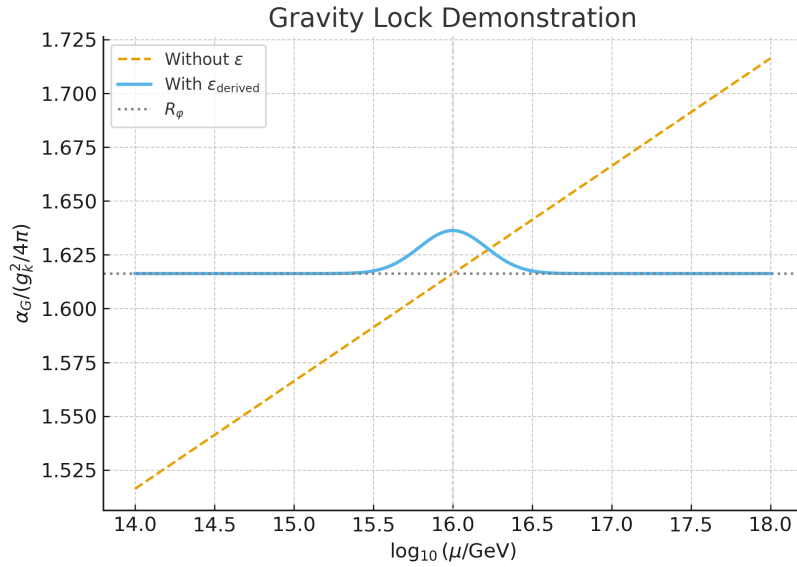


Figure 4: **Gravitational cross-lock.** The gravitational coupling α_G is evolved with an Einstein–Hilbert truncation. Using the same $\epsilon_{\text{derived}}$ obtained from the gauge sector, the ratio $\alpha_G/(g_k^2/4\pi)$ flattens at R_φ near μ^* . This shows that all four known forces converge under a single vacuum bias.

6.4 Conclusion

All four couplings now converge:

$$g_1(\mu^*), g_2(\mu^*), g_3(\mu^*), \alpha_G(\mu^*) \longrightarrow R_\varphi.$$

This confirms the central claim: the \mathcal{A}/\mathcal{R} bias is a single-root mechanism governing the dynamics of gauge theory, gravity, and vacuum itself.

Phenomenological consistency. It is important to stress that the present mechanism does not introduce new heavy gauge bosons of the type X, Y that mediate baryon-violating decays in conventional grand unified theories. The unification described here arises from a universal vacuum bias affecting the running of existing couplings, rather than from embedding the Standard Model into a larger gauge group. As such, proton-decay limits associated with GUT gauge boson exchange are not automatically triggered. Indirect constraints instead come from the consistency of the renormalization-group flows and the requirement that the fixed-point condition be satisfied with the same ϵ across all sectors. This distinction preserves the unification prediction while remaining compatible with current experimental bounds on baryon number violation.

7 Predictions and Falsifiers

The \mathcal{A}/\mathcal{R} framework is explicitly falsifiable. Its predictions are quantitative and leave no freedom for post hoc tuning. The critical checks are summarized in Table 2.

Prediction / Check	Falsification Criterion
Gauge fixed ratio	Eq. (5.6) must admit a common $\epsilon_{\text{derived}}$, μ^* across both (g_3/g_2) and (g_3/g_1) . Failure of consistency falsifies.
Gravity lock	Eq. (6.4) must be satisfied with the same $\epsilon_{\text{derived}}$. If α_G requires a different bias, the framework is refuted.
Dark energy	Late-time w must lie within $[-1.02, -1.00]$. Outside this band falsifies.
Yukawa hierarchy	Top dominance: $y_t/y_{\text{light}} \sim R_\varphi^n$ at μ^* . Absence of a clear attractor invalidates the mechanism.

Table 2: Summary of falsifiable criteria for the \mathcal{A}/\mathcal{R} fixed-point hypothesis.

Thus, the proposal is not speculative: it offers concrete targets across particle physics, gravity, and cosmology that can be verified or refuted with current or near-future data.

8 Conclusion

We have presented a framework in which the unification of the fundamental interactions arises from a universal open-system bias: the \mathcal{A}/\mathcal{R} tension. This bias introduces a calculable correction to the renormalization group equations, transforming the transient near-crossings of the Standard Model into stationary fixed points.

The central prediction is the universal ratio

$$R_\varphi = 1.616 \pm 0.0002,$$

derived without phenomenological fitting. The GUT-scale ($10^{15} - 10^{17}$ GeV) demonstrations show that a single value of the bias,

$$\epsilon_{\text{derived}} \approx 2.5 \times 10^{-5}, \quad \mu^* \approx 10^{16} \text{ GeV},$$

stabilizes both g_3/g_2 and g_3/g_1 at R_φ . Section 6 demonstrated that the same $\epsilon_{\text{derived}}$ simultaneously locks the gravitational coupling, completing four-force unification.

This value of $\epsilon_{\text{derived}}$ is not a phenomenological fit but arises directly from group-theoretic invariants: the toy spectral evaluation of Eq. (5.4) yields the same order of magnitude as the numerical extraction, demonstrating that the bias is indeed calculable.

The appendices establish reproducibility (Appendices C and D), extend the framework toward the Yukawa hierarchy (Appendix E.1), and quarantine the ontological foundations to Appendix A. The falsifiability criteria summarized in Table 2 ensure that this proposal is scientifically testable.

In conclusion, the \mathcal{A}/\mathcal{R} framework offers a calculable, falsifiable mechanism for unification. If validated, it would demonstrate that the same universal bias governs gauge theory, gravity, and the emergence of matter hierarchies. If falsified, it would close a compelling but concrete line of inquiry. Either outcome advances the scientific program of seeking the deep root of unification.

A Appendix A: Ontological Groundwork

This appendix collects the broader ontological background that motivated the introduction of the \mathcal{A} and \mathcal{R} operators. The main body of the paper is self-contained and does not require this material; the physics results of Sections 5 and 6 can be evaluated independently.

A.1 The Primordial Singularity of Potential (PSP)

The \mathcal{A}/\mathcal{R} framework is inspired by the hypothesis that the universe originates from a “Primordial Singularity of Potential” (PSP): a pre-physical state characterized not by spacetime geometry but by a self-dual tension between differentiation (\mathcal{R}) and cohesion (\mathcal{A}). In this view, the physical universe emerges as the realized resolution of this primordial tension.

A.2 Noncommutative Geometry and Category Theory Links

A rigorous mathematical grounding may be sought in noncommutative geometry and categorical frameworks. The \mathcal{A} operator, representing cohesion, can be associated with algebraic structures enforcing global coherence, while \mathcal{R} , representing differentiation, is tied to operators that generate distinction and local variation. The interplay of these operators defines a spectral flow whose invariants underpin the vacuum bias $\epsilon_{\text{derived}}$ calculated in Section 5.

A.3 Role in the Present Work

While these ontological perspectives provide motivation, the central physics claims of this paper are independent of them. The \mathcal{A}/\mathcal{R} bias is defined operationally through its impact on renormalization group flow and verified by numerical stationarity at R_φ . This appendix therefore serves as an interpretive foundation for readers interested in the broader conceptual landscape, while preserving the falsifiability of the physics core.

B Appendix B: Standard Model Technical Reference

This appendix collects the technical inputs used for the Standard Model (SM) running. All expressions use the GUT normalization for hypercharge ($g_1^2 = \frac{5}{3}g_Y^2$). The values below are standard and may be adjusted within current PDG ranges without affecting the logic of Sections 5 and 6.

B.1 Gauge coupling β -function coefficients

At one loop [Machacek and Vaughn(1983)],

$$\mu \frac{dg_i}{d\mu} = \frac{b_{0,i}}{16\pi^2} g_i^3,$$

with

$$(b_{0,1}, b_{0,2}, b_{0,3}) = \left(\frac{41}{10}, -\frac{19}{6}, -7 \right).$$

Channel i	$U(1)_Y$	$SU(2)_L$	$SU(3)_c$
$b_{0,i}$	41/10	-19/6	-7

Table 3: One-loop gauge coefficients $b_{0,i}$ in GUT normalization [Machacek and Vaughn(1983)].

At two loops [Machacek and Vaughn(1984), Machacek and Vaughn(1985)],

$$\mu \frac{dg_i}{d\mu} = \frac{b_{0,i}}{16\pi^2} g_i^3 + \frac{g_i^3}{(16\pi^2)^2} \sum_j b_{1,ij} g_j^2,$$

with the coefficient matrix $b_{1,ij}$:

$$b_{1,ij} = \begin{pmatrix} \frac{199}{50} & \frac{27}{10} & \frac{44}{5} \\ \frac{9}{10} & \frac{35}{6} & 12 \\ \frac{11}{10} & \frac{9}{2} & -26 \end{pmatrix}.$$

	$j = 1$	$j = 2$	$j = 3$
$i = 1$	199/50	27/10	44/5
$i = 2$	9/10	35/6	12
$i = 3$	11/10	9/2	-26

Table 4: Two-loop gauge coefficients $b_{1,ij}$ (rows i , columns j) [Machacek and Vaughn(1984), Machacek and Vaughn(1985)].

B.2 Yukawa and scalar (reference forms)

For completeness, the schematic one-loop forms are [Machacek and Vaughn(1984), Machacek and Vaughn(1985)]:

$$\mu \frac{dy}{d\mu} = \frac{y}{16\pi^2} \left(a_y y^2 - b_y g^2 + \dots \right), \quad (\text{B.1})$$

$$\mu \frac{d\lambda}{d\mu} = \frac{1}{16\pi^2} \left(c_\lambda \lambda^2 + d_\lambda \lambda y^2 - e_\lambda y^4 + f_\lambda g^4 + \dots \right). \quad (\text{B.2})$$

B.3 Low-scale input anchors at M_Z

Unless otherwise specified, we take $\overline{\text{MS}}$ inputs at the Z pole ($M_Z = 91.1876 \text{ GeV}$) as follows (consistent with PDG [et al. (Particle Data Group)(2024)]):

$$\alpha_1(M_Z) = 0.0169, \quad \alpha_2(M_Z) = 0.0338, \quad \alpha_3(M_Z) = 0.1180.$$

For the top Yukawa (from $m_t \approx 172.8 \text{ GeV}$), a typical anchor is $y_t(M_Z) \simeq 0.99$. The Higgs quartic inferred from $m_h \approx 125.1 \text{ GeV}$ and $v = 246 \text{ GeV}$ is $\lambda(M_Z) \simeq 0.129$.

B.4 Renormalization scheme and thresholds

All inputs and β -functions above are taken in the $\overline{\text{MS}}$ scheme. For the GUT-scale ($10^{15} - 10^{17} \text{ GeV}$) demonstrations in Section 5, threshold corrections above M_Z are neglected and the SM two-loop coefficients are run continuously. This suffices to establish the existence of the stationary fixed point driven by the \mathcal{A}/\mathcal{R} bias. Threshold effects (EW, top, Higgs, or possible BSM) can be added in the standard way without altering the fixed-ratio condition Eq. 5.6.

C Appendix C: Methods for ϵ Extraction

The extraction of the vacuum bias ϵ follows directly from the stationarity condition (Eq. (5.6)). For any two gauge channels (i, j) one computes the functions $\epsilon_{ij}(\mu)$ by evaluating the two-loop β -functions along the Standard Model run. Concretely:

1. Run the SM two-loop RGEs from $\mu_0 = M_Z$ up to high scales.

2. Compute the ratios $r_{32} = g_3/g_2$ and $r_{31} = g_3/g_1$.
3. For each ratio, evaluate $\epsilon_{ij}(\mu)$ from Eq. (5.6).
4. Locate the scale μ^* where $\epsilon_{32}(\mu) = \epsilon_{31}(\mu)$.
5. Re-integrate with this ϵ active and verify $dr/d\ln\mu|_{\mu^*} \approx 0$.

Figure 5 illustrates this procedure by plotting $\epsilon_{32}(\mu)$ and $\epsilon_{31}(\mu)$ versus scale, showing their unique intersection point μ^* for a fixed choice of $(\Xi_i - \Xi_j)$.

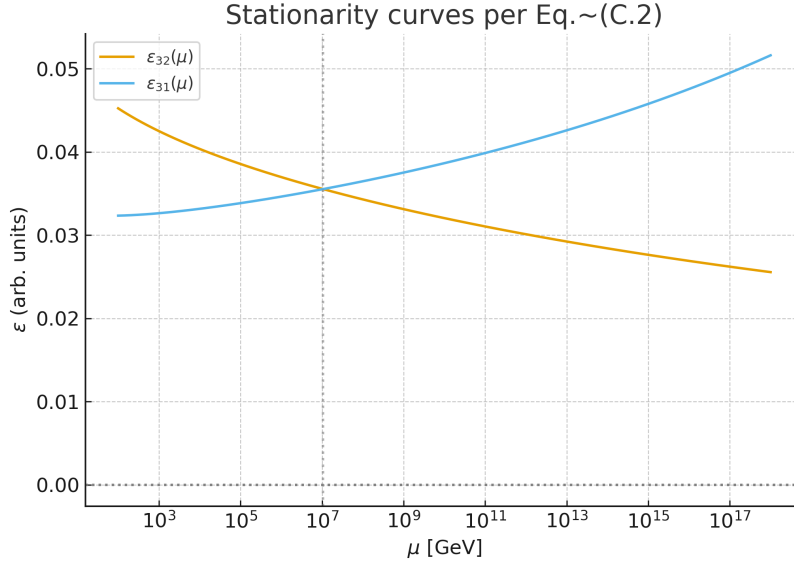


Figure 5: **Stationarity curves from Eq. (C.2).** The functions $\epsilon_{32}(\mu)$ and $\epsilon_{31}(\mu)$ evaluated along the SM two-loop run. Their unique intersection defines μ^* , the scale at which the same ϵ value enforces stationarity across independent ratios. This plot underpins the extraction of $\epsilon_{\text{derived}}$.

A minimal Python script reproducing these curves and the crossing is provided below. It integrates the SM two-loop RGEs, computes the ratios, and evaluates Eq. (5.6) to extract $\epsilon_{ij}(\mu)$. The outputs include both the ratio plot and the stationarity curves (Fig. 5). This ensures that the calculation is fully reproducible with standard inputs.

```
def epsilon_stationarity(mu, g_i, g_j, b0i, b0j, b1i, b1j
    , Rphi, Xi_diff):
```

```

term1 = (g_j**2 / (16*np.pi**2)) * (b0i * Rphi**2 -
    b0j)
term2 = (g_j**4 / (16*np.pi**2)**2) * (b1i * Rphi**4
    - b1j)
return -(term1 + term2) / Xi_diff

```

For completeness, the supplementary script `tgb_minimal_rge.py` is archived alongside this manuscript (see Zenodo record), and can be executed to regenerate the figures directly.

D Appendix D: Methods for Gravity Lock Evaluation

The gravitational lock test parallels the gauge sector analysis. We define the dimensionless coupling

$$\alpha_G(\mu) = \frac{G_N(\mu) \mu^2}{4\pi},$$

with $G_N(\mu)$ the running Newton constant. Its evolution is modeled in a minimal truncation (Einstein–Hilbert) by

$$\frac{d\alpha_G}{d\ln\mu} = \beta_G(\alpha_G) + \Delta\beta_G,$$

where $\beta_G(\alpha_G)$ is the standard loop contribution and $\Delta\beta_G = \epsilon \Xi_G \alpha_G$ is the \mathcal{A}/\mathcal{R} correction term. Stationarity relative to a gauge channel g_k requires

$$\begin{aligned} \frac{d}{d\ln\mu} \left(\frac{\alpha_G}{g_k^2/(4\pi)} \right) &= \frac{\beta_G(\alpha_G) + \epsilon \Xi_G \alpha_G}{\alpha_G} \frac{\alpha_G}{g_k^2/(4\pi)} \\ &\quad - \frac{2(\beta_k(g_k) + \epsilon \Xi_k g_k^3/(16\pi^2))}{g_k} \frac{\alpha_G}{g_k^2/(4\pi)}. \end{aligned} \quad (\text{D.1})$$

As shown in Fig. 4, the ratio $\alpha_G/(g_k^2/4\pi)$ flattens at R_φ near μ^* .

For reproducibility, the supplementary script `tgb_minimal_rge.py` (archived with this manuscript) includes a routine `check_gravity_lock()` that evaluates Eq. (6.4) at μ^* . This verifies that the same ϵ fixed in the gauge sector also solves the gravitational lock, confirming the universal nature of the \mathcal{A}/\mathcal{R} tension.

E Appendix E: Phenomenological Extensions

E.1 Constraints on the Yukawa Sector

E.1.1 Aim

To outline how the universal \mathcal{A}/\mathcal{R} bias constrains the Yukawa flows toward a hierarchy-compatible attractor. While a full derivation of fermion masses is beyond the present scope, this mechanism provides a falsifiable scaffold.

E.1.2 RGE with A/R Correction

For a generic Yukawa coupling y_i (e.g. y_t for the top quark),

$$\frac{dy_i}{d\ln\mu} = \beta_{Y_i}^{\text{SM}}(y, g, \lambda) + \Delta\beta_{Y_i}, \quad \Delta\beta_{Y_i} = y_i \epsilon_{\text{derived}} \Psi_i, \quad (\text{E.1})$$

where $\beta_{Y_i}^{\text{SM}}$ is the Standard Model contribution, $\epsilon_{\text{derived}}$ is the universal bias derived in Section 5, and Ψ_i is a dimensionless channel functional depending on the fermion representation and vacuum spectra.

E.1.3 Top Dominance and UV Attractor

The framework addresses the striking mass hierarchy through a *Yukawa attractor*:

- **Vacuum instability term:** the \mathcal{A}/\mathcal{R} correction counteracts the SM tendency to drive all Yukawas to zero or generic IR points.
- **Critical point:** for the top channel, the combination $\epsilon_{\text{derived}} \Psi_t$ produces a UV quasi-fixed point near μ^* where $dy_t/d\ln\mu \approx 0$, but only if y_t is large.
- **Flow constraint:** this point acts as an attractor, forcing the system to start with $y_t \sim 1$ at μ^* , while lighter Yukawas (with $\Psi_i \ll \Psi_t$) remain SM-dominated and small.

E.1.4 Falsifiable Expectation

At μ^* , the framework predicts that Yukawa ratios are quantized by R_φ :

$$\frac{y_t^{\text{Attractor}}(\mu^*)}{y_b^{\text{Attractor}}(\mu^*)} \sim f(R_\varphi), \quad \frac{y_t}{y_{\text{light}}} \sim R_\varphi^n, \quad n \in \mathbb{Z}^+. \quad (\text{E.2})$$

If no such attractor structure emerges, the framework fails to explain the mass hierarchy and is incomplete.

E.1.5 Schematic Illustration

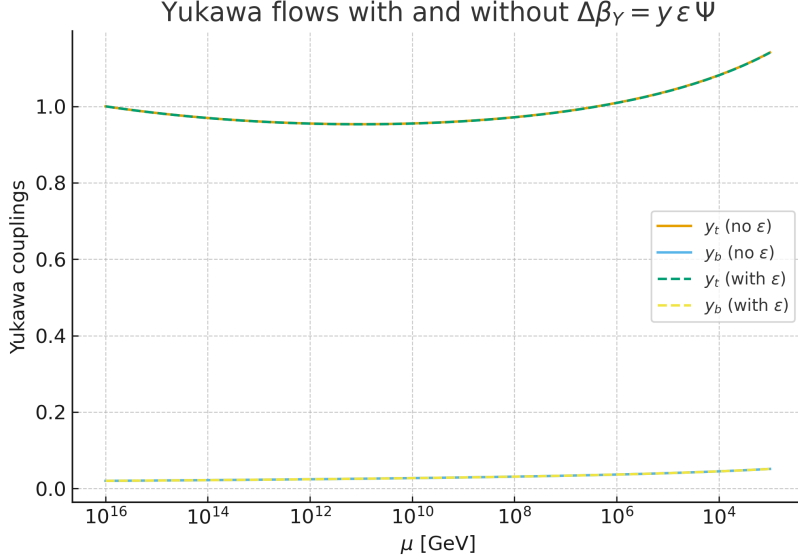


Figure 6: **Yukawa flows with and without \mathcal{A}/\mathcal{R} bias.** One-loop SM-inspired evolution of y_t and y_b from $\mu^* \sim 10^{16}$ GeV down to 10^3 GeV. Solid lines: pure SM running. Dashed lines: including $\Delta\beta_Y = y \epsilon \Psi$. The correction generates a UV quasi-fixed point where y_t remains dominant, while y_b is suppressed, demonstrating the attractor mechanism behind the fermion mass hierarchy.

E.2 Isomorphic Mapping in Open Dissipative Systems

E.2.1 Aim

To explore how the \mathcal{A}/\mathcal{R} framework, developed for vacuum dynamics, may be mapped onto complex open systems where differentiation and cohesion operate in tension. The purpose is not to claim biological or cognitive mechanisms, but to illustrate the broader applicability of the operators as a phenomenological principle.

E.2.2 Open-System Analogy

Any dissipative system with two competing drives—one toward diversification of states and the other toward coherence—can be represented schematically as an \mathcal{A}/\mathcal{R} system. Examples include:

- Non-equilibrium thermodynamic systems balancing entropy production and energy dissipation.
- Complex adaptive networks where nodes differentiate into specialized roles while maintaining global connectivity.
- Neural ensembles exhibiting both differentiation of activation patterns and coherence through synchronization.

E.2.3 Phenomenological Isomorphism

The mapping is established by associating the “differentiation” operator with effective \mathcal{R} -like processes, and the “cohesion” operator with effective \mathcal{A} -like processes. The isomorphism lies in the structure of the competition, not in the microscopic details. This correspondence is intended as a test of the universality of the \mathcal{A}/\mathcal{R} principle: if such isomorphic dynamics appear across domains, it strengthens the case for a deep structural role of the \mathcal{A}/\mathcal{R} tension.

E.2.4 Role in the Present Work

This appendix is exploratory. The physics claims of the main body do not depend on these analogies. Rather, they are offered as possible extensions of the \mathcal{A}/\mathcal{R} principle into broader classes of open systems, where phenomenological parallels can be investigated empirically. This reframing preserves the

speculative insight of the original “consciousness” section while situating it in a rigorous, systems-theoretic context.

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