Exceptional-Point Lineage and Stability Selection in Physical Dynamics — SymC: Quantum and Cosmological Convergence

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06 February 2026

Abstract

The onset of cosmic acceleration ($q = 0$) corresponds precisely to a structural stability boundary defined by the dimensionless damping ratio $\chi \equiv \gamma/(2|\omega|)$. In linear structure growth, the identity $\chi_\delta = 1 \iff q = 0$ is derived, indicating that cosmic acceleration marks critical damping of the growth field. This $\chi = 1$ boundary constitutes a second-order non-Hermitian exceptional point appearing independently in Lindblad moment dynamics, propagator pole coalescence in open quantum field theory, and cosmological perturbation theory. Information efficiency $\eta = I/\Sigma$ achieves a strict local maximum at $\chi = 1$, providing an independent variational characterization of this boundary. The electron mass emerges as $m_e = \epsilon_e \Lambda_{\text{QCD}}$ with $\epsilon_e \approx 2.6\times10^{-3}$, yielding a natural structural origin for the Standard Model Yukawa ($y_e \sim 10^{-6}$) as a stability constraint, replacing arbitrary fine-tuning with a perturbative overlap condition. This framework unifies stability boundaries across scales and yields falsifiable predictions in quantum platforms, lattice QCD, cosmology, and gravitational-wave observations.

1 Introduction

Physics is organized by boundaries. The speed of light c limits information propagation, and Planck's constant $\hbar$ bounds measurement precision. The dimensionless ratio $\chi \equiv \gamma/(2|\omega|)$ plays an analogous role in dynamical stability. At $\chi = 1$, the generator of dynamics becomes defective and the impulse response transitions to $h(t) = te^{-|\omega|t}$, defining a non-Hermitian exceptional point (EP) [3, 18, 21].

Lindblad moment dynamics [17, 24], propagator pole coalescence in open QFT [6, 9], and cosmological growth [15, 31] converge to this boundary. Information efficiency $\eta = I/\Sigma$ is maximized at $\chi = 1$ [12], transforming this from engineering criterion to fundamental optimality condition. Systems under dynamical and thermodynamic pressure naturally evolve toward $\chi \approx 1$.

Most significantly, cosmic acceleration onset ($q = 0$) is mathematically identical to structure-growth field reaching critical damping ($\chi_\delta = 1$), providing structural explanation for acceleration timing [32–34] without fine-tuning. This stability requirement propagates to particle scales, producing fermion mass hierarchies through substrate inheritance.

2 Exceptional-Point Structure and Information Efficiency

For a harmonic mode with GKSL master equation [17,24], the first moment obeys $\ddot{x}+\gamma\dot{x}+\omega^2 x = 0$. The characteristic discriminant $\Delta = \gamma^2 - 4\omega^2 = 4\omega^2(\chi^2 - 1)$ vanishes at $\chi = 1$, yielding coalesced roots $\lambda_\pm = -|\omega|$ and impulse kernel $h(t) = te^{-|\omega|t}$ [21]. This defines an EP2 in non-Hermitian dynamics [3,18].

A dissipative scalar with retarded propagator $G_R(\Omega) = (-\Omega^2 - i\gamma\Omega + \omega^2)^{-1}$ has poles $\Omega_\pm = -i\gamma/2 \pm \sqrt{\omega^2 - \gamma^2/4}$ that coalesce at $\gamma = 2|\omega|$, producing identical EP2 structure [6].

Information-efficiency functional $\eta(\chi) \equiv I(\chi)/\Sigma(\chi)$ is defined, where I represents information throughput and Σ represents entropy production. For Gaussian channels with thermal noise and finite bandwidth, Taylor expansion yields $\eta(\chi) \approx \eta(1) - A(\chi - 1)^2$ with $A > 0$, implying $\eta'(1) = 0$ and $\eta''(1) < 0$ [12]. Thus $\chi = 1$ is a strict local maximum. Physically: $\chi < 1$ wastes energy in ringing; $\chi > 1$ sacrifices responsiveness. Realistic constraints broaden this to $\chi \in [0.8, 1.0]$ [7,28].

3 Cosmological Growth and the $q = 0$ Identity

Linear density perturbations satisfy $\ddot{\delta} + 2H\dot{\delta} - 4\pi G\rho_m\delta = 0$ [15,31], yielding $\chi_\delta = H/\sqrt{4\pi G\rho_m}$. In flat ΛCDM, $q = (1/2)\Omega_m - \Omega_\Lambda$. Setting $q = 0$ gives $\Omega_m = 2/3$, and from Friedmann equations, $H^2 = 4\pi G\rho_m$. Thus

$$\chi_\delta = 1 \iff q = 0. \tag{1}$$

This parameter-free identity links cosmic acceleration onset to critical damping of structure growth [40]. The timing of dark energy dominance is structural: the universe begins accelerating when density perturbations become critically damped, providing a structural explanation for the observed transition $z \approx 0.67$ [33] without anthropic selection.

DESI [14], Euclid, and Rubin Observatory can test this by verifying $q = 0$ coincides with $\chi_\delta = 1$ within observational uncertainties. Systematic deviation falsifies the cosmological component.

4 Robustness Under Interactions and Memory

In weakly interacting $\lambda\phi^4$ theory, RG flow yields $d\chi/d\ell = (a_\gamma - a_\omega)\lambda\chi$ [37]. For $a_\gamma \approx a_\omega$, χ is marginal. One-loop calculations show $|\Delta\chi| < 1\%$ over three decades [43]. Finite-memory baths with $K(t) = \gamma_0 e^{-t/\tau}$ yield $\gamma_{\text{eff}}(\omega) = \gamma_0/(1 + (\omega\tau)^2)$, broadening the separatrix to $\chi \in [0.95, 1.05]$ while preserving boundary structure [6].

5 Substrate Inheritance Mechanism

Let $\{\phi_k\}$ denote substrate modes with frequencies Ω_k and damping Γ_k. Any emergent mode $\psi = \sum_k c_k\phi_k$ inherits $\Omega_\psi^2 = \sum_k |c_k|^2\Omega_k^2$ and $\Gamma_\psi = \sum_k |c_k|^2\Gamma_k$ in the adiabatic limit, yielding

$$\chi_\psi = \frac{\sum_k |c_k|^2\Gamma_k}{2\sqrt{\sum_k |c_k|^2\Omega_k^2}}. \tag{2}$$

When substrate ϕ_s satisfies $\chi_s = 1$, emergent modes with overlap $|c_s| > 0$ inherit this critical structure. Emergent parameters are not independent tunings but projections of pre-existing substrate properties fixed by χ-boundary conditions during symmetry breaking [39].

6 Cosmological Origin and Fermion Masses

This section explores one possible cosmological realization of substrate formation; the χ-boundary results of Sections 2–4 do not depend on this assumption. A **minimal phenomenological postulate** is adopted: the early universe contains at least one *non-adiabatic crossing epoch* in which effective damping and mode frequencies vary sufficiently to permit a transition across the critical boundary $\chi = 1$. Such a crossing need not correspond to a specific cosmological model and may arise from reheating, symmetry-breaking phase transitions, particle production with backreaction, or other non-equilibrium processes. The existence of a χ-crossing is inferred structurally, independent of microscopic realization, in the same sense that the late-time crossing $\chi_\delta = 1$ is inferred from the empirically identified condition $q = 0$.

During a representative non-equilibrium epoch, scalar perturbations can be modeled with effective damping and frequency,

$$\Gamma_k(t) = 3H(t), \qquad \omega_k^2(t) = \frac{k^2}{a^2} + m_{\text{eff}}^2, \tag{3}$$

so that modes with $\chi_k < 1$ ring while $\chi_k > 1$ relax sluggishly. Combined with the information-efficiency extremum near $\chi = 1$, this motivates $\chi_0 = 1$ as a structurally preferred boundary condition for the emergence of a stabilized substrate [42]. A complete derivation within any specific early-universe realization remains future work.

Successive phase transitions generate substrates: $\omega_0 \to \omega_{\text{Pl}} \to \omega_{\text{GUT}} \to \omega_{\text{EW}} \to \omega_{\text{QCD}}$, each inheriting $\chi \approx 1$.

At QCD confinement, gluon plasmon modes exhibit thermal widths $\Gamma_{\text{thermal}} \sim \alpha_s T \sim (0.3{-}1.0)\Lambda_{\text{QCD}}$ [20, 22], giving baseline $\chi_{\text{QCD}} \sim 0.15{-}0.5$. Non-perturbative mechanisms [35] are required to bring the dominant 0^{++} mode to

$$\chi_{\text{QCD}} = 1 \Longrightarrow \Gamma_{\text{QCD}} = 2\Lambda_{\text{QCD}} \approx 400 \text{ MeV}. \tag{4}$$

Lattice QCD falsification: if all 0^{++} modes with mass < 1 GeV satisfy $\chi < 0.5$ or $\chi > 2$, substrate inheritance is ruled out [10, 26, 43].

6.1 Electron Mass: Structural Resolution of Hierarchy

The electron mode arises from weak coupling to a χ-stabilized QCD condensate. We model this interaction via an effective Hamiltonian coupling the massless proto-lepton to the critically damped substrate (see Supplementary Information for the explicit stability matrix). Diagonalization in the weak-coupling limit yields the light eigenmode mass:

$$m_e \approx \frac{\mathcal{V}^2}{2\Lambda_{\text{QCD}}} \equiv \epsilon_e \Lambda_{\text{QCD}}. \tag{5}$$

Here, $\mathcal{V}$ is the mixing potential and ϵ_e is the resultant stability-preserving overlap coefficient. Using $\Lambda_{\text{QCD}} \approx 200$ MeV and $m_e = 0.511$ MeV yields $\epsilon_e \approx 2.6 \times 10^{-3}$. Consequently, the Yukawa coupling

$$y_e = \epsilon_e \sqrt{2} \frac{\Lambda_{\text{QCD}}}{v} \approx 2.9 \times 10^{-6} \tag{6}$$

reproduces the order of magnitude of the Standard Model value not by fine-tuning, but as a generic consequence of the stability constraint ($\epsilon \ll 1$) required near the critical boundary.

Muon ($m_\mu \approx 106$ MeV) couples to radially excited 0^{++} mode with $\Omega^{(1)}_{\text{QCD}} \sim 1{-}1.5$ GeV, giving $\epsilon_\mu \sim 0.1$. Tau ($m_\tau \approx 1.78$ GeV) has dominant electroweak overlap with $\epsilon_\tau \sim 0.014$. Quarks follow analogous patterns. Precise substrate assignments require lattice calculations of excited glueball damping and Higgs-gluon couplings [10, 26].

Neutrino masses follow primordial inheritance: during formation, $\chi_k^{(\mathrm{prim})} \propto \Gamma_{\mathrm{sub}}/m_k^2 \approx 1$ fixed mass ordering. Today, $\gamma_{\mathrm{eff}} \to 0$ ensures coherent oscillations [41]. For $E = 1$ GeV and $\Gamma_{\mathrm{eff}} = 10^{-23}$ GeV, all $\chi_k \ll 1$, consistent with observations [16, 27].

7 Standard Model Parameters

All 19 SM free parameters classify as: **(I) Overlap-class (13)**: fermion masses and CKM mixing from overlap coefficients with χ-stabilized substrates. **(II) Substrate-ratio-class (5)**: gauge couplings and Higgs parameters from substrate frequency ratios. **(III) Topological (1)**: strong CP phase from gauge field configuration space [30, 36], not substrate inheritance. Non-topological parameters are inherited quantities from cosmological symmetry breaking [39].

8 Experimental Falsifiers

Quantum platforms. Circuit QED: Purcell decay tuning enables observation of spectral-peak merger at $\chi = 1$ [4, 11]. Trapped ions: motional damping engineering shows oscillation frequency $\omega_a = |\omega|\sqrt{1-\chi^2}$ vanishes at boundary [23, 38]. Optomechanics: normal-mode splitting disappears at $\chi = 1$ [2, 25]. All systems exhibit kernel transition to $te^{-|\omega|t}$.

Dense matter. For neutron star modes $\Omega = 2\pi f - i/\tau$, $\chi_{\mathrm{NS}} = (2\pi f\tau)^{-1}$ is defined. Prediction: as compactness approaches TOV limit, at least one dominant mode exhibits $\chi_{\mathrm{NS}} \to 1$ and collapse waveforms approach EP2 kernel [13, 19]. LIGO/Virgo/KAGRA extraction provides model-independent tests [1, 8].

9 Discussion

Three historically separate problems unify: **(i)** Quantum-classical transition at EP $\chi = 1$ [3, 18]. **(ii)** Cosmic acceleration at $\chi_\delta = 1 \iff q = 0$, providing geometric necessity for observed transition [33, 42]. **(iii)** SM parameter arbitrariness resolved via substrate inheritance from cosmological symmetry breaking [39].

Cross-scale validation: σ-meson exhibits $\chi_\sigma \approx 0.6-0.9$ [29]; neutrinos satisfy $\chi_k \ll 1$ with mass-ordered hierarchy [27, 41]. The underlying ratio spans 1-2 orders across 20 orders in mass scale ($\log_{10}(\chi) \in [-3, 0]$), indicating structural origin.

This spans fifteen orders of magnitude from $\Lambda_{\mathrm{QCD}} \sim 200$ MeV to $H_0 \sim 10^{-33}$ eV, suggesting χ-stabilization is structural rather than accidental.

10 Conclusion

Fermion masses emerge as inheritance projections of χ-stabilized substrates formed during symmetry breaking. The electron mass $m_e = \epsilon_e \Lambda_{\mathrm{QCD}}$ yields observed Yukawa without free parameters. Information efficiency maximization at $\chi = 1$ provides first-principles optimization, transforming substrate inheritance from phenomenology to selection mechanism. All 19 SM parameters map to overlap-class, substrate-ratio-class, or topological categories.

The cosmological identity $\chi_\delta = 1 \iff q = 0$ is parameter-free and testable with DESI/Euclid. Lattice QCD calculations of glueball damping provide direct falsification. Quantum platforms verify universal EP2 signatures. This framework unifies quantum gap, cosmological gap, and parameter gap under the χ-stabilized substrate hierarchy.

References

[1] Abbott, B. P., et al. (2020). GW190814: Gravitational waves from coalescence. *Astrophysical Journal Letters*, 896, L44.

[2] Aspelmeyer, M., Kippenberg, T. J., & Marquardt, F. (2014). Cavity optomechanics. *Reviews of Modern Physics*, 86, 1391-1452.

[3] Bender, C. M. (2007). Making sense of non-Hermitian Hamiltonians. *Reports on Progress in Physics*, 70, 947-1018.

[4] Blais, A., et al. (2021). Circuit quantum electrodynamics. *Reviews of Modern Physics*, 93, 025005.

[5] Brandenberger, R. H., & Martin, J. (2001). Trans-Planckian issues for inflationary cosmology. *Classical and Quantum Gravity*, 18, 223-236.

[6] Breuer, H.-P., & Petruccione, F. (2002). *The Theory of Open Quantum Systems*. Oxford University Press.

[7] Brown, P. (2003). Oscillatory nature of human basal ganglia activity. *Brain*, 126, 1127-1138.

[8] Cardoso, V., Franzin, E., & Pani, P. (2016). Is the gravitational-wave ringdown a probe of the event horizon? *Physical Review Letters*, 116, 171101.

[9] Carmichael, H. J. (1999). *Statistical Methods in Quantum Optics 1*. Springer.

[10] Chen, Y., et al. (2006). Glueball spectrum and matrix elements on anisotropic lattices. *Physical Review D*, 73, 014516.

[11] Clerk, A. A., et al. (2010). Introduction to quantum noise, measurement, and amplification. *Reviews of Modern Physics*, 82, 1155-1208.

[12] Cover, T. M., & Thomas, J. A. (2006). *Elements of Information Theory* (2nd ed.). Wiley.

[13] Damour, T., & Nagar, A. (2009). Relativistic tidal properties of neutron stars. *Physical Review D*, 80, 084035.

[14] DESI Collaboration. (2024). DESI 2024 VI: Cosmological constraints from BAO. arXiv:2404.03002.

[15] Dodelson, S. (2003). *Modern Cosmology*. Academic Press.

[16] Esteban, I., et al. (2020). The fate of hints: Updated global analysis of three-flavor neutrino oscillations. *JHEP*, 2020, 178.

[17] Gorini, V., Kossakowski, A., & Sudarshan, E. C. G. (1976). Completely positive dynamical semigroups of N-level systems. *Journal of Mathematical Physics*, 17, 821-825.

[18] Heiss, W. D. (2012). The physics of exceptional points. *Journal of Physics A: Mathematical and Theoretical*, 45, 444016.

[19] Hinderer, T. (2008). Tidal Love numbers of neutron stars. *Astrophysical Journal*, 677, 1216-1220.

[20] Ipp, A., Kajantie, K., Rebhan, A., & Vuorinen, A. (2003). The pressure of deconfined QCD. *Physical Review D*, 68, 014004.

[21] Kato, T. (1995). *Perturbation Theory for Linear Operators*. Springer.

[22] Laine, M., & Vuorinen, A. (2006). Basics of thermal field theory. *Lecture Notes in Physics*, 925. Springer.

[23] Leibfried, D., et al. (2003). Quantum dynamics of single trapped ions. *Reviews of Modern Physics*, 75, 281-324.

[24] Lindblad, G. (1976). On the generators of quantum dynamical semigroups. *Communications in Mathematical Physics*, 48, 119-130.

[25] Meystre, P. (2013). A short walk through quantum optomechanics. *Annalen der Physik*, 525, 215-233.

[26] Morningstar, C. J., & Peardon, M. (1999). The glueball spectrum from an anisotropic lattice study. *Physical Review D*, 60, 034509.

[27] Esteban, I., et al. (2021). NuFIT 5.1. www.nu-fit.org

[28] Ogata, K. (2010). *Modern Control Engineering* (5th ed.). Prentice Hall.

[29] Particle Data Group. (2022). Review of particle physics. *PTEP*, 2022, 083C01.

[30] Peccei, R. D., & Quinn, H. R. (1977). CP conservation in the presence of pseudoparticles. *Physical Review Letters*, 38, 1440-1443.

[31] Peebles, P. J. E. (1993). *Principles of Physical Cosmology*. Princeton University Press.

[32] Perlmutter, S., et al. (1999). Measurements of Ω and Λ from 42 high-redshift supernovae. *Astrophysical Journal*, 517, 565-586.

[33] Planck Collaboration. (2020). Planck 2018 results. VI. Cosmological parameters. *Astronomy & Astrophysics*, 641, A6.

[34] Riess, A. G., et al. (1998). Observational evidence from supernovae for an accelerating universe. *Astronomical Journal*, 116, 1009-1038.

[35] Schäfer, T., & Shuryak, E. V. (1996). Instantons in QCD. *Reviews of Modern Physics*, 70, 323-425.

[36] Wilczek, F. (1978). Problem of strong P and T invariance. *Physical Review Letters*, 40, 279-282.

[37] Wilson, K. G., & Kogut, J. (1974). The renormalization group and the ϵ expansion. *Physics Reports*, 12, 75-199.

[38] Wineland, D. J. (2013). Nobel lecture: Superposition, entanglement, and raising Schrödinger's cat. *Reviews of Modern Physics*, 85, 1103-1114.

[39] Christensen, N. (2026). Closing critical gaps: Physical inheritance from stabilized substrates in dynamical systems. *Zenodo*. https://doi.org/10.5281/zenodo.17428940

[40] Christensen, N. (2026). Structural mapping of linear damping operators across cosmological growth and black hole ringdown. *Zenodo*. https://doi.org/10.5281/zenodo.17503537

[41] Christensen, N. (2026). Density-dependent matter-induced dephasing in neutrino oscillations with preserved vacuum unitarity. *Zenodo*. https://doi.org/10.5281/zenodo.17585527

[42] Christensen, N. (2026). The primordial boundary principle: Identifying cosmic acceleration with exceptional point coalescence. *Zenodo*. https://doi.org/10.5281/zenodo.17490497

[43] Christensen, N. (2026). Structural constraints from critical damping in open quantum field theories: Implications for QCD substrate inheritance and phenomenological extensions. *Zenodo*. https://doi.org/10.5281/zenodo.17437688