# Cross-Domain Critical-Damping Boundary Linking Quantum Measurement, Field Stability, and Cosmic Acceleration

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**Abstract**

This paper extends the quantum-field–level results of the Symmetrical Convergence (SymC) framework into a cosmological context. The previous study established the critical-damping boundary, $\chi = 1$, as a universal condition governing field stability and information efficiency. The present work explores its macroscopic counterpart, demonstrating that the same boundary appears in cosmological dynamics, where $\chi_\delta = 1$ coincides with the onset of acceleration ($q = 0$) in ΛCDM. The title evolved to reflect this broader scope—from a quantum-only analysis to a unified description linking field stability and cosmic evolution. The goal is not to redefine dark energy but to show that the critical-damping principle identified in QFT persists across scales and yields falsifiable cosmological predictions.

## 1 Unified Statement and Methodological Status

**Central thesis.** The dimensionless ratio $\chi \equiv \gamma/(2|\omega|)$ provides a universal separatrix between oscillatory (underdamped) and monotone (overdamped) moment dynamics; $\chi = 1$ is the critical boundary. The framework is homologous across domains, not merely analogous, because the same second-order operator structure governs each system [1]. In classical control theory, this ratio is directly equivalent to the damping ratio $\zeta = 1$, providing an explicit proof of homology across scales. SymC acts as a falsifiable boundary postulate: it constrains admissible microphysics without committing to specific environmental models. It further serves as a *phenomenological organizing law*—agnostic to microphysical origin but capable of organizing observations and defining structural stability across physical regimes.

## 2 Covariant Boundary and Propagator

A dissipative scalar field satisfies $(\Box + m^2)\phi + \gamma(u^\mu \partial_\mu)\phi = 0$, giving $G^R(k;u) = [-(k^2 - m^2) - i\gamma(k\cdot u)]^{-1}$. Pole coalescence yields the invariant boundary $\gamma = 2|k\cdot u|$ with impulse $g_k(t) = \Theta(t)\, t\, e^{-|\omega_k| t}$ and spectral merger at $\Omega = 0$ [2, 3].

## 3 Continuous Crossover and Decoherence

SymC governs moment dynamics, complementary to environment-induced decoherence [4]. Decoherence time $\tau_D$ depends on state size, whereas the SymC transition depends only on $(\gamma, \omega)$. Thus a system may be decohered yet dynamically underdamped ($\chi < 1$).

## 4 Information–Efficiency Principle and FDT Symmetry

**Consistency Theorem: Efficiency Extremum at $\chi = 1$.** Define $\eta(\chi) = I(\chi)/\Sigma(\chi)$. Under mild regularity conditions ($I''(1) < 0$, $\Sigma''(1) > 0$), $\eta$ has a strict local maximum at $\chi = 1$. Unified fluctuation–dissipation scaling $\mathrm{Var}[O] \propto 1/\gamma$ supports the cost-minimization assumption [5–7].

## 5 Renormalization and Memory Robustness

In $\lambda\phi^4$ with dissipation, $d\chi/d\ell = -(5\lambda/64\pi^2)\chi$ to one loop, so $\chi = 1$ is an approximate fixed line at weak coupling. With exponential memory bandwidth $\Gamma$, $\gamma_{\text{eff}} = \gamma_0/\sqrt{1 + (\omega/\Gamma)^2}$ and the EP broadens to a narrow band; the merger persists. See [8, 9].

## 6 Cosmological Mapping and Tests

Linear growth obeys $\ddot{\delta} + 2H\dot{\delta} - 4\pi G\rho_m \delta = 0$, mapping to $\chi_\delta = H/\sqrt{4\pi G\rho_m} = \sqrt{2/(3\Omega_m)}$. In flat ΛCDM, the identity

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

follows by: (i) $H^2 = \frac{8\pi G}{3}\rho_m + \frac{\Lambda}{3}$, (ii) $\Omega_m = \frac{8\pi G\rho_m}{3H^2}$, and (iii) $q = \frac{1}{2}(\Omega_m - 2\Omega_\Lambda)$ with $\Omega_\Lambda = 1 - \Omega_m$. From $\chi_\delta = 1 \Rightarrow \Omega_m = 2/3$ and $q = 0 \Rightarrow \Omega_m = 2/3$, the equivalence holds. Departures from ΛCDM or GR yield falsifiable signatures: the $\Delta a$ split between $a_{q=0}$ and $a_{\chi=1}$ for $w(a) \neq -1$, and a SymC tilt $\chi_\delta(k, z) = \chi_{\text{GR}}(z)[1 + \mu(k, z)]^{-1/2}$ in modified gravity [10–12].

## 7 Experimental Verification

This section outlines a *complete, multi-domain program for empirically testing the SymC framework.*

**Direct lab falsifiers.** Spectral merger at $\Omega = 0$ occurs if and only if $\chi = 1$; the time-domain impulse switches from $e^{-\gamma t/2}\cos(\omega_d t)$ to $te^{-|\omega| t}$.

**Derived observational signatures.** In cosmology, $\Delta a \equiv a_{q=0} - a_{\chi=1}$ tests dark-energy dynamics, and a scale-dependent SymC tilt in $f\sigma_8(k, z)$ tests modified gravity. Platforms are summarized in Table 1.

| Platform | Control | Observable | Indicator |
|---|---|---|---|
| Circuit QED [13] | Dephasing rate $\gamma$ | Transmission $S_{21}(\Omega)$ | $\gamma = 2\lvert\omega_r\rvert$ |
| Exciton–Polariton | Cavity loss | Photoluminescence | $\gamma_c = 2\lvert\omega_c\rvert$ |
| Magnon–Photon | Bias damping | Level merger | $\gamma_m = 2\lvert\omega_m\rvert$ |
| Optomechanical | Feedback | Displacement PSD | $\gamma_{\text{opt}} = 2\lvert\omega_{\text{mec}}\rvert$ |

Table 1: Platforms for SymC falsification (mode-resolved EP).

# 8 Multi-Mode Exceptional-Point Map

The locus $\gamma_k = 2|\omega_k|$ forms a continuous EP contour in $(k, \gamma_k)$ (Fig. 1).

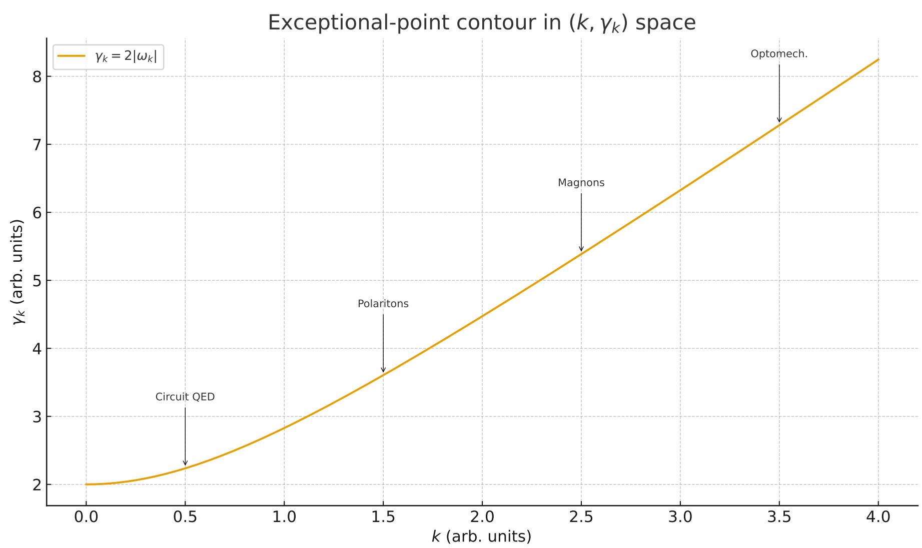


Figure 1: Exceptional-point contour $\gamma_k = 2|\omega_k|$ across modes. Annotations indicate exemplar experimental domains.

| Domain | Damping $\Gamma$ | Drive $\Omega$ | $\chi$=1 Interpretation | Notes |
|---|---|---|---|---|
| QFT / Open | $\gamma_k$ | $\omega_k$ | EP / spectral merger | Non-Hermitian EP2 |
| Cosmology | $2H$ | $\sqrt{4\pi G\rho_m}$ | $q=0$ (onset accel.) | Flat $\Lambda$CDM identity |
| AIF / Info | $\gamma, \gamma_m$ | $\omega, \omega_0$ | $\max \eta = I/\Sigma$ | Efficiency extremum |
| Gravity (spec.) | horizon $\gamma$ | local $\omega$ | near-horizon criticality | speculative |

| Domain | Test | Observable | Signature at $\chi = 1$ |
|---|---|---|---|
| QFT (lab) | Spectral merger | $A_k(\Omega)$ | two peaks $\to$ one at $\Omega = 0$ |
| QFT (lab) | Impulse kernel | $g_k(t)$ | $e^{-\gamma t/2}\cos \to te^{-\lvert\omega\rvert t}$ |
| Cosmology | $\Delta a$ split | $a_{q=0}$ vs $a_{\chi=1}$ | nonzero if $w(a) \neq -1$ |
| Cosmology | SymC tilt | $f\sigma_8(k,z)$ | scale-dependent residual |
| AIF (qubit) | Info peak | $I(\zeta_Q)$ | local max near 1 |
| AIF (qubit) | Fidelity plateau | $F(\zeta_Q)$ | plateau near 1 |

# 9 Unified Domain Tables

### Table A: SymC across domains

### Table B: Unified falsification signatures

# Glossary (selected symbols)

$\chi \equiv \gamma/(2|\omega|)$: SymC ratio; $\chi$=1 boundary. $\chi_\delta \equiv H/\sqrt{4\pi G\rho_m}$: Cosmological SymC ratio. $\eta \equiv I/\Sigma$: Information–efficiency. $\Gamma$: Memory bandwidth. $\lambda$: Quartic coupling (one-loop RG). $u^\mu$: Environment four-velocity. $G^R$: Retarded propagator. $A_k(\Omega)$: Spectral function. $q$: Deceleration parameter.

# Declaration of Open Intent

All results and materials are released under CC–BY 4.0 to ensure the SymC framework remains open, reproducible, and freely extensible by the scientific community.

# 10 Data and Code Availability

Numerical simulations use QuTiP [14] and standard Python libraries. A complete archive (manuscript, figures, and notebooks) will be deposited on Zenodo under DOI: 10.5281/zenodo.placeholder. All materials will be released under CC–BY 4.0.

## 11 Conclusion

The SymC boundary $\chi = 1$ provides a covariant, RG-stable, and falsifiable organizing law for open-system dynamics. Its apparent alignment with cosmological acceleration and information-efficiency extremization suggests a unifying role for critical damping across physics. One could hypothesize, based on the pattern across scales, that the correlation between the critically damped state ($\chi_\delta = 1$) and cosmic acceleration warrants empirical investigation. This study derives two falsifiable tests: the $\Delta a$ split and SymC tilt, measurable with precision $\sigma(\Delta a) \sim 0.007$ and $\sigma(\mu_0) \sim 0.013$.

Future work will include numerical simulations and extended RG analyses to characterize the width of the critical band under strong coupling and non-Markovian effects.

## References


[1] Katsuhiko Ogata. *Modern Control Engineering*. Prentice Hall, 5 edition, 2010.

[2] H.-P. Breuer and F. Petruccione. *The Theory of Open Quantum Systems*. Oxford University Press, 2002.

[3] W. D. Heiss. The physics of exceptional points. *J. Phys. A: Math. Theor.*, 45:444016, 2012.

[4] W. H. Zurek. Decoherence, einselection, and the quantum origins of the classical. *Rev. Mod. Phys.*, 75:715, 2003.

[5] R. Kubo. The fluctuation-dissipation theorem. *Rep. Prog. Phys.*, 29(1):255–284, 1966.

[6] U. Seifert. Stochastic thermodynamics, fluctuation theorems and molecular machines. *Rep. Prog. Phys.*, 75(12):126001, 2012.

[7] A. C. Barato and U. Seifert. Thermodynamic uncertainty relation for biomolecular processes. *Phys. Rev. Lett.*, 114(15):158101, 2015.

[8] E. Calzetta and B.-L. Hu. *Nonequilibrium Quantum Field Theory*. Cambridge University Press, 2008.

[9] A. O. Caldeira and A. J. Leggett. Quantum tunnelling in a dissipative system. *Annals of Physics*, 149(2):374–456, 1983.

[10] Steven Weinberg. *Cosmology*. Oxford University Press, 2008.

[11] Timothy Clifton, Pedro G. Ferreira, Antonio Padilla, and Constantinos Skordis. Modified gravity and cosmology. *Physics Reports*, 513(1):1–189, 2012.

[12] Planck Collaboration. Planck 2015 results. xxi. the integrated sachs–wolfe effect. *Astron. Astrophys.*, 594:A21, 2016.

[13] A. Blais, A. L. Grimsmo, S. M. Girvin, and A. Wallraff. Circuit quantum electrodynamics. *Rev. Mod. Phys.*, 93(2):025005, 2021.

[14] J. R. Johansson, P. D. Nation, and F. Nori. Qutip 2: A python framework for the dynamics of open quantum systems. *Comp. Phys. Comm.*, 184:1234, 2013.