Time Crystals, Holography, and Quantum Information: A Minimal Coherence Framework

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Abstract

We present a compact synthesis connecting Floquet time-crystal dynamics, holographic coarse-graining, and operator-level coherence constraints. The goal is not to claim a final theory but to formalize a minimal testable scaffold that separates established results from speculative bridges. We introduce an effective coherence functional and derive practical falsification hooks for numerical and experimental workflows.

Keywords time crystals; Floquet dynamics; holography; quantum information; coherence operators

1 Introduction

Time-crystal discourse often mixes distinct regimes: rigorous no-go statements in equilibrium, non-equilibrium Floquet order, and information-theoretic interpretations. This manuscript imposes a minimal common language so each claim can be attached to assumptions, observables, and failure modes.

2 Minimal Formal Layer

Let ρ_t denote a reduced state on a finite operator algebra. We define a periodic coherence witness over one drive period T:

$$\mathcal{C}_T = \frac{1}{T} \int_0^T \mathrm{Tr}[\rho_t \, \mathcal{O}_c] \, dt, \tag{1}$$

where $\mathcal{O}_c$ is a bounded coherence-sensitive observable.

For a stroboscopic map Φ_T, persistence under perturbation family $\{\epsilon\}$ is tracked by

$$\Delta_\epsilon = |\mathcal{C}_T(\epsilon) - \mathcal{C}_T(0)| . \tag{2}$$

A practical robustness criterion is

$$\sup_{\epsilon \in [0, \epsilon_0]} \Delta_\epsilon < \delta_* . \tag{3}$$

3 Holographic Interpretation Layer

We model coarse-grained reconstruction by an effective channel $\mathcal{R}$ acting on low-energy observables. A consistency requirement between boundary witness and reconstructed bulk proxy is

$$\left| \mathcal{C}_T^{\partial} - \mathcal{C}_T^{\text{bulk}} \right| \leq \eta, \tag{4}$$

with η explicitly reported as model error, not absorbed into interpretation.

4 Validation and Falsification Hooks

- **Numerical hook:** sweep drive-noise amplitude and test violation of the robustness bound.

- **Model hook:** replace $\mathcal{O}_c$ by orthogonal witness families; check whether conclusions are basis-dependent.

- **Interpretation hook:** force $\eta \to 0$ in controlled toy models; reject holographic claim if mismatch persists.

5 Conclusion

This paper provides a cleaner publication-ready baseline: assumptions are explicit, equations are readable, and each interpretive step is paired with a concrete failure condition.

References (working set)

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