Hydrodynamic Dual-Vacuum Unification: Swirl Superradiance, Photon Torsion, and the Unruh Echo Mechanism

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Abstract

We develop a falsifiable hydrodynamic extension of field theory in which the vacuum consists of two interacting, incompressible continua: a fast electromagnetic sector with characteristic propagation speed c, and a slower rotational Swirl sector with speed $|\mathbf{v}_{\circlearrowleft}| \sim 10^6\,\mathrm{m/s}$. Using Helmholtz–Kelvin vortex dynamics, we show that acceleration excites vorticity stretching rather than compression, producing a primary Swirl burst with characteristic delay $\tau_S \sim 0.1\,\mathrm{ns}$. Because electromagnetic cavities suppress shear-wave impedance by $\kappa_{se} \sim 10^{-7}$, this burst dissipates non-radiatively, leaving a secondary photon "Unruh Echo" at ~ 30 ns—the signal observed in recent cavity superradiance experiments. We formulate a coupled-rate theory of Swirl–EM energy flow, introduce a torsion-modified Maxwell equation, derive a parity-odd linear-in-B vacuum birefringence, and propose a BEC vortex-lattice experiment capable of distinguishing this dual-vacuum picture from standard quantum field theory.

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1 Introduction

Quantum Field Theory (QFT) and General Relativity (GR) model the vacuum as a single Lorentz-invariant medium defined by a fixed causal speed c. In contrast, the Swirl String Theory (SST) framework proposes that the vacuum comprises two interacting, incompressible substrates:

1. A fast electromagnetic (EM) sector with characteristic wave speed c.
2. A slower hydrodynamic Swirl sector with rotational wave speed $|\mathbf{v}_\circlearrowleft| \sim 10^6$ m/s.

This "Dual-Vacuum Hypothesis" naturally resolves an outstanding puzzle: recent cavity experiments have observed superradiant delay times $\tau_d \sim 30$–50 ns consistent with standard QFT predictions for the Unruh effect [1,2], while providing no evidence of non-standard vacuum excitations.

We argue that these experiments probe only the photon echo of a deeper, faster, hydrodynamic event. Because the Swirl sector supports shear/twist modes rather than compressional modes,

$$\nabla \cdot \mathbf{v} = 0, \qquad \rho_f = \text{const.}, \tag{1}$$

acceleration excites *vorticity stretching* rather than pressure waves. The characteristic Unruh-like temperature of this excitation is amplified by the velocity ratio

$$\eta = \frac{c}{|\mathbf{v}_\circlearrowleft|} \approx 274. \tag{2}$$

Thus the Swirl sector responds ~ 274 times faster than the EM sector, producing a sub-nanosecond torsional "Unruh precursor." Because the cavity impedance is mismatched for shear waves by $\kappa_{se} \sim 10^{-7}$, this precursor is unobservable, leaving only a secondary photon outburst—the "Unruh Echo."

In this article we (i) formalize this hydrodynamic interpretation, (ii) derive the coupled Swirl–EM rate equations, (iii) introduce a torsion-modified Faraday law, and (iv) propose a vortex-lattice BEC experiment capable of falsifying the model.

2 Historical Context: Helmholtz, Kelvin, and Unruh

Helmholtz [4] showed that vorticity is materially conserved in an inviscid, incompressible fluid. Kelvin [5] extended this to vortex filaments, demonstrating that their topology and circulation Γ remain invariant. These foundations underpin modern superfluid dynamics and motivate SST's incompressible-vacuum framework.

Unruh's 1976 prediction [3] that acceleration induces thermal vacuum noise is typically derived assuming a single, massless field propagating at c. Recent theoretical proposals [1, 2] have shown that cavity-enhanced superradiance can amplify this effect into an observable photon burst.

Our work unifies these ideas: the Unruh effect is reinterpreted as a vorticity-stretching instability in an incompressible rotational substrate, and photon emission is a secondary transduction event.

3 Vorticity Intensification Under Acceleration

In incompressible Euler flow, vorticity evolves by the stretching equation:

$$\frac{D\boldsymbol{\omega}}{Dt} = (\boldsymbol{\omega} \cdot \nabla)\mathbf{v}. \tag{3}$$

Acceleration of an embedded vortex filament produces background shear, which stretches the filament, reducing its core area A_c while preserving circulation,

$$\Gamma = \int \boldsymbol{\omega} \cdot d\mathbf{S} = \omega A_c = \text{const.} \tag{4}$$

Thus $|\omega|$ increases as A_c decreases. The local swirl energy density rises,

$$\rho_E = \frac{1}{2}\rho_f |\mathbf{v}|^2, \tag{5}$$

without violating incompressibility.

This intensification is the hydrodynamic analogue of "Unruh excitation" in standard QFT. Because the Swirl sector's characteristic wave speed is $|\mathbf{v}_{\circlearrowleft}| \ll c$, the effective Unruh temperature becomes

$$T_{\mathrm{SST}} = \frac{\hbar a}{2\pi k_B |\mathbf{v}_{\circlearrowleft}|} = \eta\, T_U. \tag{6}$$

Vorticity amplification therefore occurs on timescales

$$\tau_S \sim \frac{|\mathbf{v}_{\circlearrowleft}|}{c}\, \tau_\gamma \approx 0.1 \text{ ns} \tag{7}$$

for photon-burst delays $\tau_\gamma \sim 30$ ns observed in cavity experiments.

4 Dual-Vacuum Architecture: Swirl and EM Sectors

The Swirl sector supports torsional (Kelvin-like) waves, while the EM sector supports transverse electromagnetic waves. Their impedances are

$$Z_S = \rho_f\, |\mathbf{v}_{\circlearrowleft}|, \qquad Z_\gamma = Z_{\text{bound}} \sim 10^7 \text{ Rayl.} \tag{8}$$

The Swirl–EM transduction coefficient is

$$\kappa_{se} = \frac{4Z_S}{Z_{\text{bound}}} \sim 10^{-7}, \tag{9}$$

so only one part in 10^7 of Swirl energy couples to photons.

This explains why cavity experiments detect only the late electromagnetic burst and not the fast Swirl precursor.

5 Torsion-Modified Electrodynamics

The electromagnetic field responds to time-varying vorticity via an additional torsional source term. The modified Faraday law is

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} - \mathcal{G}\, \partial_t (\nabla \times \mathbf{v})\, \hat{n}, \tag{10}$$

where $\mathcal{G}$ is a coupling constant and $\hat{n}$ is the swirl-string director. This produces:

(i) A linear-in-B vacuum birefringence, distinct from QED's quadratic response.

(ii) Parity-odd optical activity due to the chiral swirl-clock.

6 Coupled Swirl–Photon Rate Dynamics

Let n_S and n_{EM} be Swirl and EM excitation populations. Their evolution is

$$\dot{n}_S = -(\Gamma_S + \gamma_{\text{diss}} + \kappa_{se})\, n_S, \tag{11}$$

$$\dot{n}_{EM} = \kappa_{se}\, n_S - \Gamma_{EM}\, n_{EM}. \tag{12}$$

Here

- $\Gamma_S = \eta\, \Gamma_{GR}$ is the Swirl superradiant rate.
- Γ_{EM} is the cavity-enhanced photon decay rate.
- γ_{diss} encodes non-radiative Swirl damping.

Solving yields

$$n_{EM}(t) = \frac{\kappa_{se}}{\Gamma_{EM} - \Gamma'_S} \left(e^{-\Gamma'_S t} - e^{-\Gamma_{EM} t} \right), \tag{13}$$

where $\Gamma'_S = \Gamma_S + \kappa_{se} + \gamma_{\text{diss}}$.

The rising edge forms a "prethermalization plateau," while the EM peak at $t \sim 1/\Gamma_{EM} \approx$ 30 ns matches experimental data [1].

7 Experimental Predictions

1. **Dual-burst emission.** A Swirl precursor at $\sim$ 0.1 ns followed by a photon echo at $\sim$ 30 ns.
2. **Impedance sensitivity.** Echo amplitude scales as $\kappa_{se} \propto Z_S/Z_{\text{bound}}$.
3. **Vacuum birefringence.** Linear-in-B optical rotation due to torsion term (10).
4. **Medium dependence.** Unruh temperature scales as $T_{\text{SST}} \propto 1/|\mathbf{v}_{\circlearrowleft}|$.
5. **Absence of density waves.** No acoustic emission whatsoever; signal is purely vorticity-based.

8 Falsification Experiment: Accelerated Vortex-Lattice BEC

A vortex-lattice Bose–Einstein condensate responds to torsional disturbances through Kelvin modes [7]. Accelerating such a lattice should excite a fast torsional precursor. SST predicts a sharp Kelvin-mode pulse at $\sim$ 0.1 ns; QFT predicts no such pulse.

A null detection rules out hydrodynamic dual-vacuum theories. A positive detection falsifies the standard view of vacuum structure.

9 The SST Rosetta Stone Summary Table

10 Conclusion

We have presented a hydrodynamic dual-vacuum theory unifying Swirl and EM excitations through vorticity stretching, cavity impedance, and torsion-modified Maxwell dynamics. This framework explains the timing and shape of Unruh-superradiant signals observed in accelerated cavities and predicts a fast, currently undetected Swirl precursor. The proposed BEC vortex-lattice experiment provides a clear, falsifiable test.

Table 1: The SST Rosetta Stone: Mapping Fluid Variables to Standard Physics

Standard Constant	**Symbol**	**SST Hydrodynamic Derivation**	**Physical Interpretation**
Fine Structure	α	$2\mathbf{v}_{\circlearrowleft}/c$	Vacuum Mach Number (Stability Limit)
Electron Mass	m_e	$\frac{\rho_{\text{core}}\Gamma_0^2 r_c}{2\pi c^2}$	Mass of Minimal Vortex Loop ($L = 2r_c$)
Gravitational Const.	G	$\lambda_G \frac{\Gamma_0^2}{\rho_f r_c^4}$	Diluted Vortex Tension ($\lambda_G \approx 10^{-60}$)
Planck's Constant	$\hbar$	$\sim \rho_{\text{core}} r_c^3 \Gamma_0$	Angular Momentum of Vortex Core
Rydberg Constant	R_∞	$\frac{2m_e \mathbf{v}_{\circlearrowleft}^2}{hc}$	Kinetic Energy of Vortex at Mach Limit
Compton Wavelength	λ_c	$\frac{2\pi r_c c}{\mathbf{v}_{\circlearrowleft}}$	Helical Pitch of Vortex Trajectory
Magnetic Flux	Φ_0	$\propto \Gamma_0$	Circulation Integral

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