

# Unifying Electromagnetism Gravity and Quantum Geometry via Incompressible Hydrodynamics

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## Abstract

We present a unified field theory based on the hydrodynamics of an inviscid, incompressible, director-bearing fluid substrate. We demonstrate that Relativistic kinematic effects emerge naturally from circulation conservation: proper time dilation is derived as a function of fluid circulation  $\Gamma^{1111}$ , while effective mass arises from rotational kinetic energy density  $\Delta\rho_{eff}^2$ . We identify the photon not as a point particle, but as a propagating torsion wave (shear wave) within this substrate, predicting a vacuum Faraday effect<sup>33</sup> recently supported by experimental data on optical magnetic torques (Assouline Capua, 2025). Furthermore, we show that steady-swirl Euler pressure gradients yield a short-range  $1/r^3$  force for filamentary  $v_\theta \propto 1/r$ , while the long-range inverse-square law arises from a local mediator obeying a Poisson equation on  $\mathbb{R}^3$ ,<sup>4</sup>, and that the fundamental electron scales  $(r_e, \omega_C, E_B)$  satisfy a precise harmonic identity derived from this hydrodynamic coupling<sup>555</sup>.

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# 1 Introduction

The quest to unify interactions suggests that the vacuum is not an empty void, but a structured medium. Building on the "Vortex Atom" hypothesis of Kelvin<sup>6</sup> and modern superfluid vacuum analogies<sup>7</sup>, we propose **Swirl String Theory (SST)**. In SST, physical laws are emergent properties of a background fluid with effective density  $\rho_f$  and shear stiffness  $\mathcal{K}$ .

## 2 Kinematics: Circulation as Local Time

Standard Special Relativity (SR) posits time dilation as a function of relative velocity. We reformulate this in terms of fluid topology. For a clock co-moving with an inviscid fluid in rigid rotation, the tangential velocity  $v$  is linked to the circulation  $\Gamma = \oint \mathbf{v} \cdot d\mathbf{l}$ <sup>8</sup>.

Substituting  $v = \Gamma/(2\pi r)$  into the Minkowski metric yields a circulation-based time dilation<sup>9</sup>:

$$\frac{d\tau}{dt} = \sqrt{1 - \frac{\Gamma^2}{4\pi^2 r^2 c^2}} \quad (1)$$

Because  $\Gamma$  is conserved in inviscid, barotropic flows (Kelvin's Theorem), time dilation becomes a topological invariant of the flow<sup>10</sup>. This suggests that "time" is a measure of the local vorticity density of the vacuum substrate.

## 3 The Origin of Mass: Rotational Energy Density

Mass is not intrinsic but emergent. By analyzing a fluid in rigid-body rotation, we calculate the volume-averaged rotational kinetic energy density  $\langle e_{kin} \rangle$ <sup>11</sup>. Applying the mass-energy equivalence  $E = mc^2$ , we derive an effective mass density relation<sup>12</sup>:

$$\frac{\Delta\rho_{eff}}{\rho} = \frac{1}{4} \left( \frac{v_{edge}}{c} \right)^2 \quad (2)$$

This confirms that rotational motion contributes to the inertial mass of extended systems at order  $(v/c)^2$ <sup>13</sup>. In SST, fundamental particles are modeled as knotted vortex loops<sup>14</sup>. These loops possess finite energy, impulse, and an effective mass  $M_{eff} = \|I\|/U$  defined by their hydrodynamic impulse  $I$  and self-induced velocity  $U$ <sup>15</sup>.

## 4 Electromagnetism: Photons as Torsion Waves

We reject the point-particle photon. Using Cartan's structure equations in a teleparallel geometry, we identify the electromagnetic field tensor  $F_{\mu\nu}$  as the projection of the substrate's torsion 2-form  $T^a$ <sup>16</sup>. The photon emerges as a massless transverse shear wave of the substrate's director field<sup>17</sup>.

The wave speed is determined by the substrate's effective stiffness and density<sup>18</sup>:

$$c = \sqrt{\frac{\mathcal{K}}{\rho_{eff}}} \quad (3)$$

A key prediction of this hydrodynamic model is the Vacuum Faraday Effect, where the vacuum exhibits a linear-in- $B$  magnetic optical response<sup>19</sup>.

**External Validation:** This hydrodynamic mechanism is strongly supported by recent findings by Assouline & Capua (2025), who demonstrated that the optical magnetic field contributes significantly to the Faraday effect, distinct from the electrical component, particularly at ultra-fast timescales<sup>20</sup>. This breaks the classical reciprocity of the vacuum, exactly as predicted by SST when the local swirl velocity (time scaling) is perturbed.

## 5 Emergent Gravity (Corrected): near-field Euler vs far-field mediator

Steady, axisymmetric Euler balance gives

$$\frac{1}{\rho} \frac{dp}{dr} = -\frac{v_\theta^2(r)}{r}.$$

For filamentary circulation  $v_\theta = \Gamma/(2\pi r)$  this implies  $dp/dr \propto -1/r^3$  and therefore a pressure deficit  $\Delta p \propto -1/r^2$ , yielding forces  $\propto 1/r^3$ . This is a *short-range* interaction and does not produce a Newtonian inverse-square law.

Long-range gravity is modeled by a local mediator  $\phi$  (clock/foliation mode) with static action

$$S_{\text{stat}}[\phi] = \int d^3x \left[ \frac{\kappa}{2} (\nabla\phi)^2 - \lambda \rho_m(\mathbf{x}) \phi \right], \quad \kappa \nabla^2 \phi = -\lambda \rho_m,$$

whose Green-function solution for localized sources gives  $\phi(r) \propto 1/r$  and hence  $|\nabla\phi| \propto 1/r^2$ .

## 6 The Grand Unified Scale Identity

The consistency of SST is verified by a single harmonic identity connecting classical, relativistic, and atomic scales. We derive a maximal Hooke-law force  $F_{\text{max}}$  using the electron mass  $m_e$ , Compton frequency  $\omega_C$ , and fine-structure constant  $\alpha$ <sup>25</sup>:

$$F_{\text{max}} = m_e \left( \frac{\omega_C}{\alpha} \right)^2 r_e \quad (4)$$

Multiplying this force by a Compton-scale radius  $r_c$ , we recover the Hydrogen ground state energy  $E_B$  and the electron rest mass exactly<sup>26</sup>:

$$F_{\text{max}} r_c = \frac{1}{2} m_e c^2 = \frac{E_B}{\alpha^2} \quad (5)$$

This identity serves as the "Rosetta Stone" of SST, proving that atomic structure ( $E_B$ ), relativity ( $c$ ), and electrodynamics ( $\alpha$ ) are geometrically coupled via the fluid properties of the vacuum.

## 7 Conclusion

By treating the vacuum as a physical fluid, we have unified proper time dilation, effective mass, electromagnetism, and gravity under a single hydrodynamic framework. The recent observation of optical magnetic torque (Assouline & Capua, 2025) provides the necessary empirical bridge between this hydrodynamic theory and modern magneto-optics.

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