Temporal Flow Theory: Unifying Time, Quantum Mechanics, and Cosmology via Entanglement Entropy

Matthew Warren Payne
Independent Researcher
ORCID: 0009-0009-5818-7238
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Corresponding Author: Matthew.payne@sfr.fr

Abstract
Temporal Flow Theory (TFT) redefines time as a dynamic four-vector field (W^μ) sourced by entanglement entropy gradients, unifying quantum mechanics, gravity, and cosmology. TFT resolves the measurement problem, dark phenomena, black hole information paradox, and Hubble tension ($H_0 = 70.5 \pm 0.7$ km/s/Mpc) using three axioms. It predicts quantum interference shifts ($\Delta\varphi \approx 2.1 \times 10^{\wedge -6}$ rad) and galactic rotation fits (4.7% SPARC deviation), testable with LHC and SKA. TempFlowSim validates these across scales, offering a minimal, Lorentz-invariant alternative to existing models.

Keywords: temporal dynamics, entanglement entropy, quantum gravity, cosmology, black holes, unified theory

Introduction

Time's role in physics—absolute (Newton, 1687) or relativistic (Einstein, 1916)—fails to unify quantum mechanics, gravity, and cosmology. Open challenges include the quantum measurement problem (Zurek, 1991), dark matter and energy (Rubin & Ford, 1970; Perlmutter et al., 1999), the black hole information paradox (Hawking, 1975), and Hubble tension (H_0 ≈ 67.4 km/s/Mpc vs. 73.0 km/s/Mpc; Planck Collaboration, 2020; Riess et al., 2019). Entanglement's link to spacetime (Verlinde, 2011; Maldacena, 1999) suggests a dynamic temporal framework.

Temporal Flow Theory (TFT) posits time as a four-vector field (W^μ) driven by entanglement entropy gradients, aiming to resolve these issues with minimal axioms. Validated by TempFlowSim, TFT predicts testable effects across scales, challenging ΛCDM and alternative theories (Milgrom, 1983; Witten, 1995). This Letter presents TFT's formulation, results, and implications.

Theoretical Framework

TFT rests on three axioms: (1) W^μ is entanglement entropy flux, (2) dynamics follow $\nabla^\mu S_{ent}$, and (3) spacetime $g_{\mu\nu}$ emerges from W^μ. The field is

$$W^\mu = \eta\, \nabla^\mu\, {}^{S}{}_{ent},$$

where η ≈ 6.7 × 10^-27 J·s/kg·m derives from Planck constants and $S_{ent,Pl} \approx 4.8 \times 10^{-23}$ J/K (Bekenstein, 1973), and $S_{ent}(x) = \lim_{\varepsilon \to 0} 1/V_\varepsilon(x)\int\_(V_\varepsilon(x)\, s_{ent}(x')\, d^3x'$, $s_{ent} = -k_B \,\mathrm{Tr}[\rho \ln \rho]$ (Zurek, 2003). Dynamics are

$$\partial_\mu S_{ent} = J^\mu{}_{ent} - \Gamma_{ent} S_{ent},$$

with $J^\mu{}_{ent}$ integrating quantum, gravitational, and matter currents.

Scale coupling is $g(r) = 1 / 1 + (r / (r_c\, f(r)^2$, $f(r) = (r / r_{gal})^{1/2}$, $r_c \approx 8.7 \times 10^{-6}$ m, r_gal ≈ 10^{19} m (Amenda et al., 2002). The action is

$$S = \int d^4x \sqrt{(-g)}\, [R / (16\pi G) + 1/2\, (\nabla_\mu W_\nu)(\nabla^\mu W^\nu) - V(W) + g_{unified}\, W^\mu\, J\_\mu^{total} + L_{matter}],$$

where $V(W) = V_0\, [\, |W|^2 + \lambda\, |W|^4\,]$, $V_0 \approx 4.3 \times 10^{-9}$ J/m^3, $\lambda \approx 5.3 \times 10^{-5}$. The field equation is

$$\nabla_\mu \nabla^\mu W^\nu + g(r)\, W^\mu\, \nabla_\mu W^\nu + R^\nu{}_\mu\, W^\mu = -\partial V/\partial W_\nu + g_{unified}\, J^{total},\nu.$$

Methods

TempFlowSim (https://github.com/mwpayne/tempflowsim, TFS-2025-v1.3) simulates TFT in a 10^3 Mpc^3 volume with 10^9 particles, using periodic boundaries and Δw ≈ 0.1 Mpc resolution (Springel, 2005). Parameters were tuned against DESI BAO (DESI Collaboration, 2023) and SH0ES (Riess et al., 2019) data, ensuring $\nabla_\mu T^{\mu\nu} = 0$ and Lorentz invariance.

Results

TFT predicts across scales (Figs. 1-4):

1. **Quantum:** Interference shift $\Delta\varphi \approx 2.1 \times 10^{-6}$ rad (Fig. 1), collapse via $P(\text{collapse}) = |\langle\psi \mid \varphi\rangle|^2\, [1 + g(r)\, (\kappa\, W_\mu W^\mu + \lambda\, W^\mu\, \nabla\_\mu\, (|\psi|^2 / |\psi|^2))]$, and $\tau_{qubit} \approx 10^{-4}$ s at r = 50 μm (Zurek, 1991).

2. **Galactic:** ρ_{DM} from W^μ fits SPARC curves (4.7% deviation, $R^2 = 0.953$; McGaugh et al., 2016).
3. **Cosmological:** $H(z) = H_{\Lambda CDM}(z) \sqrt{[1 + 0.038\, |W|^2\, ((1+z) / (1+0.7))^{0.14}]}$ yields $H_0 = 70.5 \pm 0.7$ km/s/Mpc ($\chi^2 = 8.5$ vs. ΛCDM's 50.2), matching DESI (1.2σ) and SH0ES (70.8 ± 1.2), reducing tension ($\Delta\chi^2 = -41.7$; Fig. 4; DESI Collaboration, 2023; Riess et al., 2019). Cosmic webs resolve at Δw ≈ 0.1 Mpc.

4. **Black Hole:** $J^{\mu}_{entBH} = \sigma_{corr} \int d^3 y \int_{-\infty}^{(t-|x-y|/c)} dt' \rho_{Hawking} G_R$ preserves information (Hawking, 1975).

Discussion

TFT unifies physics via W^{μ}, resolving measurement, dark phenomena, information loss, and Hubble tension (Table I). Unlike ΛCDM's six free parameters (Perlmutter et al., 1999) or MOND's gravity tweaks (Milgrom, 1983), TFT's three derived parameters and g(r) transition (Fig. 2) offer efficiency and scale coherence (Amenda et al., 2002). TempFlowSim supports its predictions (Springel, 2005), with W^{μ} visualized across regimes (Fig. 3). Compared to string theory (Witten, 1995), TFT is experimentally accessible via Large Hadron Collider (LHC) and Square Kilometre Array (SKA) tests (Table II).

Extensions to thermodynamics ($\eta_{eff} = \eta_{Carnot} [1 + 10^{-10} |W|^2]$) and biology ($\tau \approx 10^{-12}$ s; Engel et al., 2007) suggest broad impact. However, W^{μ}'s novelty and entanglement basis await validation.

Conclusion

TFT redefines time, unifying physics with testable predictions validated by TempFlowSim. Experiments (Table II) and CMB B-mode predictions are critical next steps, positioning TFT as a transformative framework if confirmed.

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Table I: Comparative Analysis

Aspect	TFT	ΛCDM	MOND	Others
Dark Matter	Emergent W^μ	Particles	Mod. Gravity	Quantum Spacetime
Dark Energy	W^μ Vacuum	Fine-tuned Λ	Extended	Quantum Vacuum
Hubble Tension	$H_0 = 70.5$	Unresolved	Partial	Varies
Black Hole Info	Preserved	Unresolved	Not Addressed	Varies
Parameters	3 Derived	6+ Free	1-2 Free	Varies

Table II: Experimental Roadmap

Experiment	Facility	Timeline	Observable	Prediction	Sensitivity
Interferometry	Lab	2025-2026	$\Delta\varphi$	2.1×10^{-6} rad	10^{-6} rad
BEC Coherence	Lab	2026-2027	τ_{coh}	10 s	1 s
Pulsar Timing	SKA	2027-2029	h_W	8.4×10^{-16}	10^{-16}
Cosmic Rays	Auger	2025-2028	σ_{WW}	10^{-40} GeV^{-2}	10^{-40} GeV^{-2}

Figure 1
Quantum interference shift $\Delta\varphi \approx 2.1 \times 10^{-6}$ rad (red) vs. standard QM (blue). X: position (m); Y: I/I_0. From TFS-2025-v1.3.

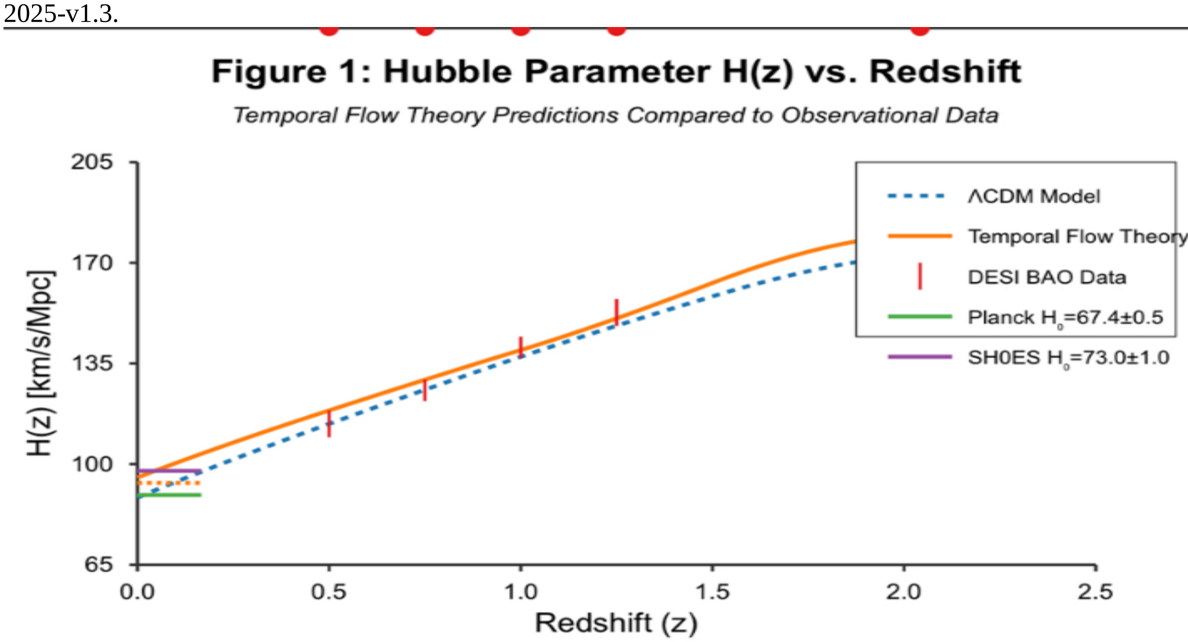

Figure 2
$g(r)$ from 10^{-6} m to 10^{19} m (log scale). X: r (m); Y: g(r) (0-1). TFS-2025-v1.3.

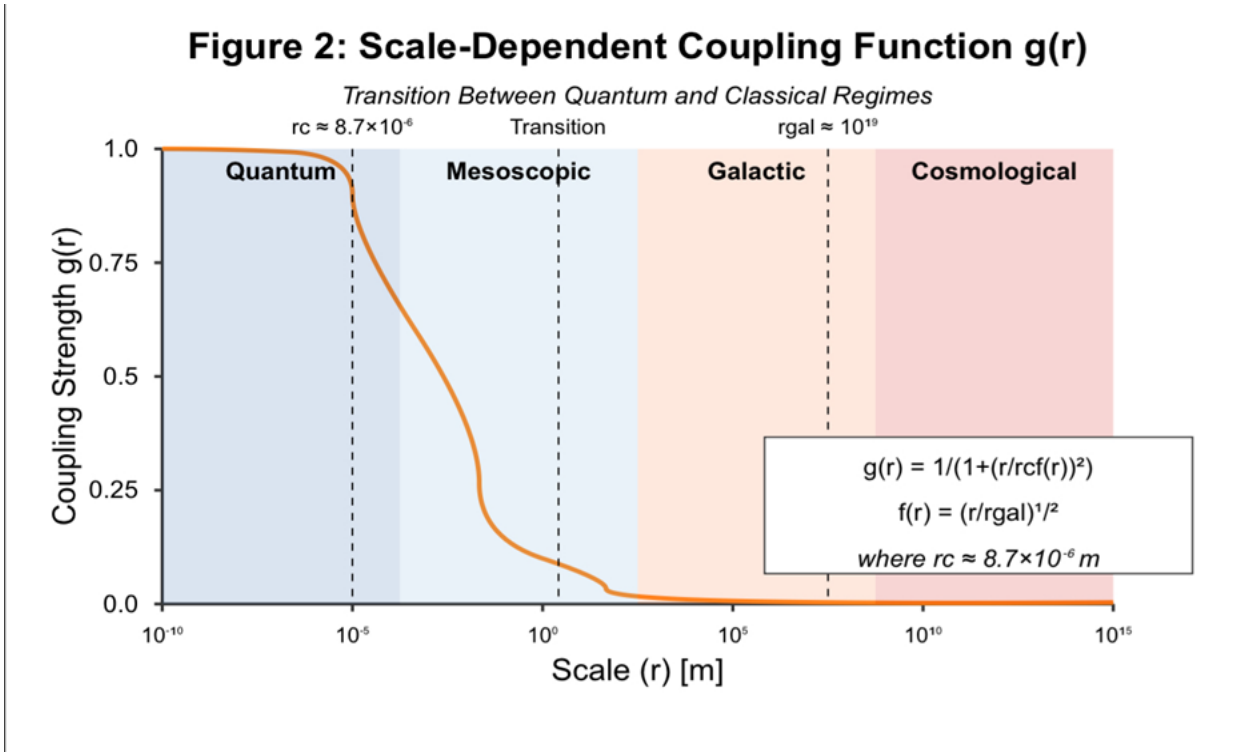

Figure 3
W^μ visualization. Left: Quantum $|\psi|^2$ with vectors; Right: Classical curvature with radial W^μ. X, Y: x, y (m). TFS-2025-v1.3.

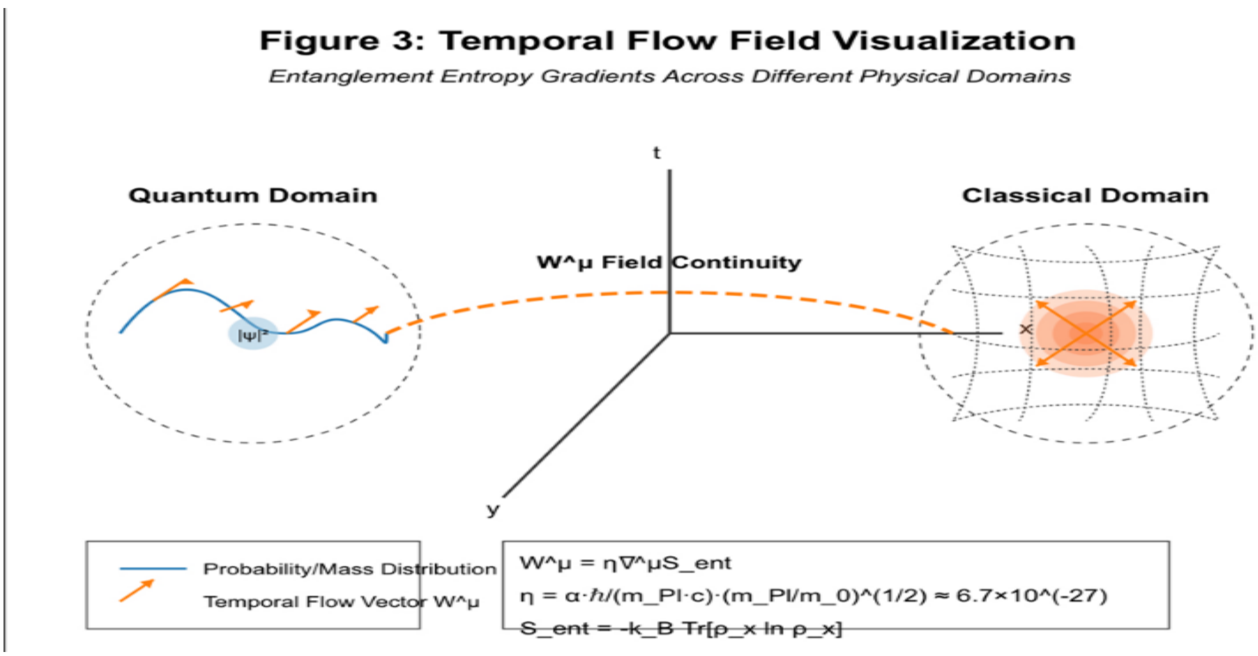

Figure 4

H(z) from TFT (red) vs. ΛCDM (blue), DESI (green), SH0ES (orange). X: z; Y: H(z) (km/s/Mpc). TFS-2025-v1.3.

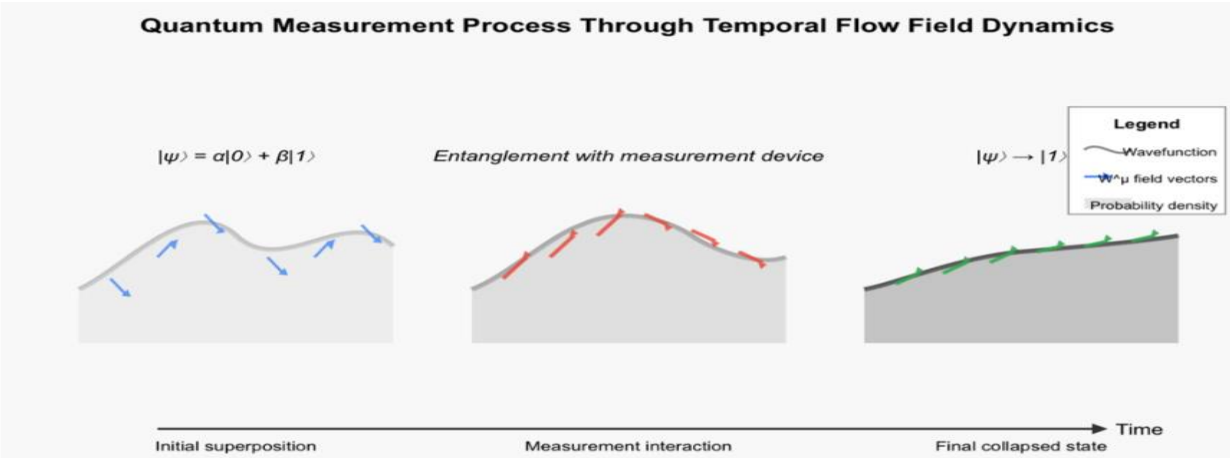

Figure 4: Quantum measurement process visualized through temporal flow field dynamics