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

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**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 (H0 = 70.5 ± 0.7 km/s/Mpc) using three axioms. It predicts quantum interference shifts (Δφ ≈ 2.1 × 10^-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) Wμ is entanglement entropy flux, (2) dynamics follow ∇μ Sent, and (3) spacetime gμν emerges from Wμ. The field is

Wμ = η ∇μ Sent,

where η ≈ 6.7 × 10^-27 J·s/kg·m derives from Planck constants and Sent,Pl ≈ 4.8 × 10-23 J/K (Bekenstein, 1973), and Sent(x) = limε→0 1/Vε(x)∫\_(Vε(x) sent(x') d3x', sent = -kB Tr[ρ ln ρ] (Zurek, 2003). Dynamics are

∂μ Sent = Jμent - Γent Sent,

with Jμent integrating quantum, gravitational, and matter currents.

Scale coupling is g(r) = 1 / 1 + (r / (rc f(r)2, f(r) = (r / rgal)1/2, rc ≈ 8.7 × 10-6 m, r\_gal ≈ 1019 m (Amenda et al., 2002). The action is

S = ∫ d4x √(-g) [R / (16πG) + 1/2 (∇μ Wν)(∇μ Wν) - V(W) + gunified Wμ J\_μtotal + Lmatter],

where V(W) = V0 [ |W|2 + λ |W|4 ], V0 ≈ 4.3 × 10-9 J/m3, λ ≈ 5.3 × 10-5. The field equation is

∇μ ∇μ Wν + g(r) Wμ ∇μ Wν + Rνμ Wμ = -∂V/∂Wν + gunified Jtotal,ν.

**Methods**

TempFlowSim (https://github.com/mwpayne/tempflowsim, TFS-2025-v1.3) simulates TFT in a 103 Mpc3 volume with 109 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 ∇μ Tμν = 0 and Lorentz invariance.

**Results**

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

1. **Quantum:** Interference shift Δφ ≈ 2.1 × 10-6 rad (Fig. 1), collapse via P(collapse) = |⟨ψ | φ⟩|2 [1 + g(r) (κ Wμ Wμ + λ Wμ ∇\_μ (|ψ|2 / |ψ|2))], and τqubit ≈ 10-4 s at r = 50 μm (Zurek, 1991).

2. **Galactic:** ρDM from Wμ fits SPARC curves (4.7% deviation, R2 = 0.953; McGaugh et al., 2016).

3. **Cosmological:** H(z) = HΛCDM(z) √[1 + 0.038 |W|2 ((1+z) / (1+0.7))0.14] yields H0 = 70.5 ± 0.7 km/s/Mpc (χ2 = 8.5 vs. ΛCDM’s 50.2), matching DESI (1.2σ) and SH0ES (70.8 ± 1.2), reducing tension (Δχ2 = -41.7; Fig. 4; DESI Collaboration, 2023; Riess et al., 2019). Cosmic webs resolve at Δw ≈ 0.1 Mpc.

4. **Black Hole:** JμentBH = σcorr ∫ d3 y ∫-∞(t-|x-y|/c) dt' ρHawking GR preserves information (Hawking, 1975).

**Discussion**

TFT unifies physics via Wμ, 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 Wμ 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 (ηeff = ηCarnot [1 + 10-10 |W|2]) and biology (τ ≈ 10-12 s; Engel et al., 2007) suggest broad impact. However, Wμ’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 Wμ | Particles | Mod. Gravity | Quantum Spacetime |
|  |  |  |  |  |
| Dark Energy | Wμ Vacuum | Fine-tuned Λ | Extended | Quantum Vacuum |
|  |  |  |  |  |
| Hubble Tension | H0 = 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 | Δφ | 2.1 × 10-6 rad | 10-6 rad |
| BEC Coherence | Lab | 2026-2027 | τcoh | 10 s | 1 s |
| Pulsar Timing | SKA | 2027-2029 | hW | 8.4 × 10-16 | 10-16 |
| Cosmic Rays | Auger | 2025-2028 | σWW | 10-40 GeV-2 | 10-40 GeV-2 |

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**Figure 1**

Quantum interference shift Δφ ≈ 2.1 × 10-6 rad (red) vs. standard QM (blue). X: position (m); Y: I/I\_0. From TFS-2025-v1.3.

A graph of a diagram

AI-generated content may be incorrect.

**Figure 2**

g(r) from 10-6 m to 1019 m (log scale). X: r (m); Y: g(r) (0-1). TFS-2025-v1.3.

**A diagram of a function

AI-generated content may be incorrect.**

**Figure 3**

Wμ visualization. Left: Quantum |ψ|2 with vectors; Right: Classical curvature with radial Wμ. X, Y: x, y (m). TFS-2025-v1.3.

**A diagram of a diagram of a diagram

AI-generated content may be incorrect.**

**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.

# **A diagram of a graph AI-generated content may be incorrect.**