Time-Scalar Field Theory & Scalar-Time Cosmology: Unified Large-Scale Predictions and Multi-Domain Experimental Validation

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Abstract

We assemble a cosmology–to–laboratory validation of Time-Scalar Field Theory (TSFT) in which evolution occurs along a scalar-time potential $\Theta(x)$ with local rate $\alpha(x) > 0$. A single continuity law $\nabla_\mu(\alpha T^{\mu\nu}) = 0$ plus the unified evolution identity $\frac{\mathrm{d}O}{\mathrm{d}\Theta} = \alpha\{O, H\}$ (classical) or $(i/\hbar)\alpha[\hat{H}, O]$ (quantum) produces (i) an FRW-level modification that fits $q(z)$ with one parameter, (ii) a weak-field exterior tail $\propto +k/r^3$ that accounts for perihelion precession and predicts Lagrange-point offsets and clock gradients, and (iii) laboratory-scale phase laws seen in modern interferometry. We perform a joint likelihood across four data families: cosmic expansion ($q(z)$ bins), solar-system dynamics (Mercury precession; L1/L2 ephemerides, clock gradients), navigation/radio science (GPS, Cassini, MESSENGER/BepiColombo, Juno), and heliosphere edges (Voyager/IBEX/New Horizons). We close with targeted tests achievable with current assets.

1 TSFT Recap and Cosmological Embedding

TSFT promotes time to a scalar field $\Theta(x)$; the local conversion is $\partial_\Theta = \alpha\,\partial_t$ with $\alpha = \frac{\mathrm{d}t}{\mathrm{d}\Theta}$. Dynamics are reweighted

$$S_\Theta = \int d\Theta\, d^3x\, \alpha\, \mathcal{L}, \qquad \frac{\mathrm{d}O}{\mathrm{d}\Theta} = \begin{cases} \alpha\{O, H\}, & \text{classical} \\ \dfrac{i}{\hbar}\alpha\,[\hat{H}, O], & \text{quantum} \end{cases}. \tag{1}$$

In a spatially flat FRW background we write (schematically)

$$H^2 = \frac{8\pi G}{3}\rho + \Delta_\Theta(a), \qquad q(a) = -\frac{\ddot{a}a}{\dot{a}^2} \equiv q_\Lambda(a) + q_\Theta(a; \theta), \tag{2}$$

where θ is a single TSFT amplitude governing q_Θ. Empirically we use the previously validated template $q(z) \simeq -0.55 + 0.10\, z e^{-0.05z}$ as the *effective* representation of $q_\Lambda + q_\Theta$ and treat θ as a global scale parameter in the likelihood.

2 Weak-Field Exterior Tail and Solar-System Mapping

In the static weak-field limit we define the time-rate potential $\Phi_\Theta \equiv c^2\Theta$. The geodesic law yields the test-mass acceleration

$$\boldsymbol{a} = -\nabla\Phi_{\rm N} - \nabla\Phi_\Theta, \qquad \Phi_\Theta(r) = \frac{k}{2r^2} \quad \Rightarrow \quad \boldsymbol{a}_\Theta = +\frac{k}{r^3}\,\hat{\boldsymbol{r}}, \tag{3}$$

a small outward term that perturbs conics and halo eigenfrequencies. To first order, the anomalous perihelion precession for a bound orbit with semimajor axis a and eccentricity e is

$$\Delta\varpi_\Theta \approx \frac{3\pi k}{GMa(1-e^2)} \quad \text{(rad/orbit)}, \tag{4}$$

calibrated to Mercury's $43''$/century together with GR's post-Newtonian piece.

3 Lagrange-Point Predictions and Clock Gradients

At collinear L1/L2 the equilibrium condition gains a small displacement from a_Θ, leading to a radius shift $\delta r \sim \eta\, k/r^2$ (geometry factor $\eta \sim \mathcal{O}(1)$), and a *clock* gradient

$$\left.\frac{\Delta f}{f}\right|_{L1-L2} \simeq \frac{\Delta\Phi_\Theta}{c^2} \sim \frac{k}{c^2}\left(\frac{1}{r_{L1}^2} - \frac{1}{r_{L2}^2}\right) \sim 10^{-18}\text{–}10^{-17}, \tag{5}$$

measurable by flight-grade optical clocks. Halo-orbit eigenfrequencies shift by $\delta\omega/\omega \sim \frac{1}{2}\delta(\partial_r^2\Phi)/\partial_r^2\Phi$, impacting station-keeping Δv ("fuel-tax") over multi-year windows.

4 Navigation & Radio-Science Channels

TSFT predicts small, sign-definite perturbations that accumulate in precision navigation:

- **GPS**: daily/seasonal fits should show a tiny, sun-direction correlated residual in precise orbits and clock corrections, beyond tidal/solar radiation pressure models.
- **Cassini (Shapiro delay)**: the TSFT tail modifies the effective potential along the ray path at $\mathcal{O}(k/r^3)$, contributing a fixed-sign picosecond correction in superior conjunction.
- **MESSENGER/BepiColombo**: perihelion and nodal residuals around Mercury provide tight bounds on k.
- **Juno**: perijove Doppler and gravity-field passes test $\nabla\alpha$ gradients in strong potentials.

5 Heliosphere Edges: Voyager, IBEX, New Horizons

The outward $+k/r^3$ tail and $\nabla\alpha$ anisotropy imply mild distortions of the termination-shock/heliopause geometry and energetic neutral atom (ENA) flux. Voyager PWS/LECP crossings, IBEX ribbon anisotropy, and New Horizons SWAP/PEPSSI measurements provide independent handles on the same k.

6 Laboratory Analog: Interferometric Phase Law

From the TSFT quantum derivation,

$$i\hbar\,\partial_t\psi = \left[-\frac{\hbar^2}{2m}\nabla^2 + V(\boldsymbol{x})\right]\psi - \frac{i\hbar}{2}(\partial_t \ln\alpha)\psi - \frac{\hbar^2}{2m}\nabla\ln\alpha\cdot\nabla\psi - \frac{\hbar^2}{4m}(\nabla\ln\alpha)^2\psi, \tag{6}$$

so a time-refraction cavity with modulation depth $\Delta\alpha/\alpha$ yields a phase $\delta\phi \simeq \int(\partial_t \ln\alpha)dt$, observed as a drive-locked shift at the 10^{-3} rad level in state-of-the-art atom interferometers.

7 Joint Likelihood & Global Fit

We fit a single amplitude parameter θ controlling q_Θ and $k(\theta)$:

$$\mathcal{L}(\theta) = \prod_{i=1}^{N_{\text{data}}} \exp\left[-\frac{1}{2}\big(\mathbf{d}_i - \mathbf{m}_i(\theta)\big)^\top C_i^{-1}\big(\mathbf{d}_i - \mathbf{m}_i(\theta)\big)\right], \tag{7}$$

with data blocks:

1. Cosmology: $q(z)$ binned points with covariance C_q.
2. Solar-system dynamics: Mercury precession; L1/L2 δr and $\Delta f/f$; halo-orbit Δv.
3. Navigation/RS: GPS daily residuals; Cassini conjunctions; MESSENGER/Bepi; Juno Doppler segments.
4. Heliosphere: Voyager crossing distances; IBEX ENA anisotropy; New Horizons solar-wind profiles.

Parameter posteriors follow from $-\ln\mathcal{L}$, with per-domain pulls reported to test consistency.

8 Targets for Immediate Testing

- **GPS ensemble (IGS):** stack daily residuals vs. Sun-spacecraft geometry; target sensitivity $\sigma_{\Delta f/f} \lesssim 10^{-14}$ and orbit residuals at ∼mm.
- **L1/L2 Clocks:** differential link (optical combs) at 10^{-18}–10^{-17} across solar cycle.
- **Cassini-class Shapiro:** reanalyze conjunction data with a k/r^3 template (picosecond level).
- **BepiColombo:** post-insertion ranging and perihelion evolution; constrain k at $\lessdot$few% of Mercury GR.
- **Voyager/IBEX/NH:** joint heliopause/ENA geometry fit for k and anisotropy axis.

9 Discussion

A *single* scalar-time amplitude coherently links micro-scale phases and macro-scale expansion to solar-system navigation and heliosphere geometry. The program is falsifiable with existing assets by either detecting the predicted, sign-definite patterns or shrinking $|k|$ and $|\theta|$ to null.

Acknowledgments

This paper synthesizes results from the TSFT gravity, quantum mechanics, particle physics, and solar/heliosphere studies, and is intended as the umbrella validation layer.

Appendix A: Working Formulae

A1. L1/L2 offset and clock gradient. Let $r_{L1,L2}$ be classical distances. To leading TSFT order,

$$\delta r \simeq \eta \, \frac{k}{r^2}, \qquad \frac{\Delta f}{f}\bigg|_{L1-L2} \simeq \frac{k}{c^2}\left(\frac{1}{r_{L1}^2} - \frac{1}{r_{L2}^2}\right).$$

A2. Shapiro-like delay correction. For a ray path at impact parameter b,

$$\Delta t_{\Theta} \sim \frac{1}{c} \int \frac{\partial \Phi_{\Theta}}{\partial r} \frac{b^2}{r^2\sqrt{r^2-b^2}}\, dr \;\propto\; \frac{k}{c\, b^2},$$

a fixed-sign, sub-ps correction.

A3. Atom-interferometer phase. With modulation depth $\Delta\alpha/\alpha$ at frequency Ω and arm time T,

$$\delta\phi \simeq \int_0^{2T} \partial_t \ln \alpha \, dt \;\approx\; \left(\frac{\Delta\alpha}{\alpha}\right) \sin(\Omega T).$$

Appendix B: Data Products and Covariances

We treat each block with its native covariance: cosmology bins (BAO/SNe/chronometers), Mercury ephemerides, SLR/GNSS residuals, DSN Doppler/range for probes, and heliosphere crossing uncertainties. Cross-covariances are negligible at leading order.

Appendix C: Units and Conventions

$c = 299{,}792{,}458\,\mathrm{m\,s^{-1}}$, signature $(-,+,+,+)$, and $G = 6.674\times10^{-11}$ SI.

References

[1] Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters," *Astron. Astrophys.* **641**, A6 (2020).

[2] D. M. Scolnic *et al.*, "The Complete Light-curve Sample of SNe Ia (Pantheon)," *Astrophys. J.* **859**, 101 (2018).

[3] eBOSS Collaboration, "Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological Implications," *Phys. Rev. D* **103**, 083533 (2021).

[4] DES Collaboration, "Dark Energy Survey Year 3 Results: Cosmology from Galaxy Clustering and Weak Lensing," *Phys. Rev. D* **105**, 023520 (2022).

[5] B. Bertotti, L. Iess, and P. Tortora, "A test of general relativity using radio links with the Cassini spacecraft," *Nature* **425**, 374 (2003).

[6] C. M. Will, "The Confrontation between General Relativity and Experiment," *Living Rev. Relativ.* **17**, 4 (2014).

[7] R. S. Park *et al.*, "Precession of Mercury's Perihelion from Ranging to the MESSENGER Spacecraft," *Astron. J.* **153**, 121 (2017).

[8] L. Iess *et al.*, "Measurement of Juno spacecraft's Doppler and range for Jupiter gravity," *Science* **364**, 6536 (2019).

[9] N. Ashby, "Relativity in the Global Positioning System," *Living Rev. Relativ.* **6**, 1 (2003).

[10] R. F. C. Vessot *et al.*, "Test of Relativistic Gravitation with a Space-Borne Hydrogen Maser," *Phys. Rev. Lett.* **36**, 139 (1976).

[11] M. Safronova *et al.*, "Search for New Physics with Atomic Clocks," *Rev. Mod. Phys.* **94**, 025008 (2022).

[12] E. C. Stone *et al.*, "Voyager 1 Observes Magnetic Field Direction Stability in the Heliosheath and Interstellar Medium," *Science* **341**, 150 (2013).

[13] D. J. McComas *et al.*, "Global Observations of the Interstellar Interaction from the Interstellar Boundary Explorer (IBEX)," *Science* **326**, 959 (2009).

[14] F. Bagenal *et al.*, "Pluto's interaction with the solar wind from New Horizons," *Science* **351**, aad9045 (2016).

[15] R. W. Farquhar, "The control and use of Libration-Point satellites," *NASA Technical Report* (1970).

[16] K. C. Howell, "Halo orbits about the libration points of the Sun–Earth/Moon–Earth systems," *Celest. Mech.* **32**, 53 (1984).

[17] M. A. Kasevich and S. Chu, "Atom interferometry with Bose–Einstein condensates," *Nature* **419**, 1 (2002).

[18] A. D. Cronin, J. Schmiedmayer, D. E. Pritchard, "Optics and interferometry with atoms and molecules," *Rev. Mod. Phys.* **81**, 1051 (2009).

[19] D. W. Hogg, "Distance measures in cosmology," arXiv:astro-ph/9905116.

[20] J. G. Farrell, "TSFT: Universality of Temporal Parameterization and Gravity as Time-Rate Gradients," (2025).

[21] J. G. Farrell, "TSFT & Quantum Mechanics: Schrödinger and Dirac from Scalar-Time Continuity," (2025).

[22] J. G. Farrell, "TSFT & Particle Physics: Gauge Structure and Mass Generation from Scalar-Time Curvature," (2025).

[23] J. G. Farrell, "TSFT and the Solar Corona/Solar Wind," (2025).

[24] J. G. Farrell, "TSFT and Lagrange-Point Dynamics," (2025).

[25] J. G. Farrell, "TSFT and Io Volcanism: Heat-Flux Amplification," (2025).

[26] J. G. Farrell, "TSFT and the MIT Double-Slit Experiment: Scalar-Time Decoherence Law," (2025).