# Time-Field Dynamics: A Scalar-First Approach to Gravitation

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**Abstract**

We develop a class of theories in which physical time is treated as a dynamical scalar field $\tau(\mathbf{x}, t)$ rather than a coordinate or part of an a priori metric. In the non-relativistic limit, a simple wave equation for $\tau$ sourced by rest-mass density, combined with the constitutive law $\mathbf{a} = -\gamma\nabla\tau$ for test bodies, exactly reproduces Newtonian gravity with an inverse-square law. Clock rates and light propagation are controlled by the local value of $\tau$ via tunable functions $F(\tau)$ and $n(\tau)$. In the weak-field regime the pure scalar version recovers precisely the "Newtonian half" of the observed gravitational light deflection ($2GM/c^2b$ instead of General Relativity's $4GM/c^2b$), illustrating the need for genuine tensorial spatial curvature. The natural covariant uplift belongs to the Einstein-Æther family with a unit timelike vector $u^\mu$. Modern constraints (notably GW170817) force any viable version into an extremely narrow region of parameter space near General Relativity. While the scalar toy model is falsified by precision tests, the interpretational shift—treating the time-field as ontologically primary and the metric as emergent—offers a fresh perspective on Lorentz-violating vector-tensor theories.

**Keywords:** gravitation, scalar gravity, Einstein-aether theory, modified gravity, preferred frame, emergent metric

## 1 Introduction and Core Ontology

Conventional approaches to gravity begin with a spacetime metric $g_{\mu\nu}$ as the fundamental dynamical object. Here we reverse the ontological priority: physical time is primary and is represented by a scalar field $\tau(\mathbf{x}, t)$ carrying units of proper-time rate (dimensions of frequency). Space remains flat and Euclidean at the fundamental level; any effective spatial curvature must emerge from the dynamics of $\tau$ or additional structure.

This philosophy echoes early attempts at scalar gravity [1, 2], but differs crucially from Nordström's conformally flat second theory (which predicts zero light deflection). Instead our light-bending arises from a spatially varying refractive index $n(\tau)$, yielding exactly half the General Relativity value—a well-known intermediate case between Nordström and Einstein.

The non-relativistic axioms are:

1. Physical time is a scalar field $\tau(\mathbf{x}, t)$.

2. Matter resists gradients of $\tau$: $\mathbf{a} = -\gamma\nabla\tau \quad (\gamma > 0)$.

3. Clock rates $\nu = \nu_0 F(\tau)$ and refractive index $n(\tau)$ depend on the local value of $\tau$.

4. $\tau$ obeys a wave equation sourced by rest-mass density $\rho$ with finite propagation speed $c_\tau$.

## 2 Minimal Non-Relativistic Action

We posit the action

$$S = S_\tau + S_{\text{matter}} + S_{\text{int}}, \tag{1}$$

$$S_\tau = -\frac{1}{2\kappa}\int \left(|\nabla\tau|^2 - \frac{1}{c_\tau^2}\dot{\tau}^2\right) d^3x\,dt, \tag{2}$$

$$S_{\text{int}} = -\alpha \int \rho\,\tau\, d^3x\,dt, \tag{3}$$

$$S_{\text{matter}} = \int \left(\frac{1}{2}\rho v^2 - \rho\Phi_{\text{ext}}\right) d^3x\,dt, \tag{4}$$

with $\kappa > 0$ (positive kinetic energy) and $c_\tau^2 > 0$.

Variation with respect to $\tau$ yields

$$\boxed{\nabla^2\tau - \frac{1}{c_\tau^2}\partial_t^2\tau = \kappa\alpha\rho.} \tag{F}$$

The constitutive law for matter particles is postulated (or derivable from a relativistic completion) as

$$\boxed{\mathbf{a} = -\gamma\nabla\tau \quad (\gamma > 0).} \tag{E}$$

## 3 Static Solution and Newtonian Limit

In the static limit, $\nabla^2\tau = \kappa\alpha\rho$. For a point mass $M$,

$$\tau(r) = \tau_\infty + \frac{\kappa\alpha M}{4\pi r} \equiv \tau_\infty + \frac{C}{r}, \quad C \equiv \frac{\kappa\alpha M}{4\pi}. \tag{5}$$

Then

$$\mathbf{a} = -\gamma\nabla\tau = -\gamma\frac{C}{r^2}\hat{\mathbf{r}}. \tag{6}$$

Defining Newton's constant via

$$G \equiv \frac{\gamma\kappa\alpha}{4\pi} \quad \Rightarrow \quad C = \frac{GM}{\gamma} \tag{7}$$

reproduces exactly $\mathbf{a} = -GM/r^2\,\hat{\mathbf{r}}$. The inverse-square form is the generic consequence of Gauss's law for a massless scalar in flat 3+1-dimensional spacetime with 3 spatial dimensions.

## 4 Clock Rates and Light Propagation

Weak-field expansions:

$$F(\tau) \approx 1 + \beta(\tau - \tau_\infty), \tag{8}$$

$$n(\tau) = 1 + \eta(\tau - \tau_\infty) = 1 + \eta\frac{C}{r}. \tag{9}$$

### 4.1 Light Deflection (explicit)

Consider a ray with impact parameter $b$ grazing the mass (unperturbed trajectory $x = b$, $y = 0$, $z = t$). The small-gradient deflection formula is

$$\delta\theta \approx \int_{-\infty}^{\infty} \partial_x n\, dz. \tag{10}$$

We have

$$\partial_x n = -\eta C \frac{x}{r^3}, \quad r = \sqrt{b^2 + z^2}. \tag{11}$$

Evaluating on the unperturbed ray ($x = b$),

$$\delta\theta = -\eta C b \int_{-\infty}^{\infty} \frac{dz}{(b^2 + z^2)^{3/2}} = -\eta C b \cdot \frac{2}{b^2} = -\frac{2\eta C}{b}. \tag{12}$$

Magnitude:

$$\boxed{\delta\theta = \frac{2\eta C}{b} = \frac{2\eta}{\gamma} \frac{GM}{b}.} \tag{13}$$

Choosing natural units $\gamma = 1$ and $\eta = 1/c^2$ yields

$$\delta\theta = \frac{2GM}{c^2 b} \quad \text{(pure scalar prediction)}, \tag{14}$$

exactly half the General Relativity result $4GM/c^2 b$ [10, 9].

### 4.2 Shapiro Delay

Coordinate travel time along a path $L$:

$$t \approx \int_L n(\tau)\, ds \approx \int_L ds + \eta C \int_L \frac{ds}{r(s)}. \tag{15}$$

The observable delay thus scales with $\eta$, while gravitational redshift scales with $\beta$. General Relativity requires $\eta = \beta = 1/c^2$; in the pure scalar theory these are independent, so simultaneous agreement is non-generic.

## 5 Observable Discriminants

| Observable | Pure Scalar | GR | Current Precision | Passes? |
|---|---|---|---|---|
| Light deflection (weak field) | $2GM/c^2 b$ | $4GM/c^2 b$ | $\lesssim 10^{-4}$ (GAIA/VLBI) | No |
| Shapiro delay | tunable coefficient | $4GM/c^3 \ln(4 r_w r_e)$ | $10^{-5}$ (Cassini) | No* |
| Perihelion precession | 0 (1PN) | $43''$/cy (Mercury) | $\sim 10^{-3}$ | No |
| Frame-dragging | none | GP-B value | 0.3% | No |
| GW speed/polarization | scalar, speed $c_\tau$ | tensor, speed $c$ | $\lvert c_T - c\rvert/c \lesssim 10^{-15}$ | No |

Table 1: *Only by artificial tuning of $\eta/\beta$.

## 6 Covariant Uplift: Einstein-Æther

Promoting $\tau$ to a unit timelike vector $u^\mu$ ($u^\mu u_\mu = -1$) yields the Einstein-Æther action [3, 4]

$$S = \frac{1}{16\pi G_\star} \int \sqrt{-g}\left[R - K^{\mu\nu}{}_{\alpha\beta} \nabla_\mu u^\alpha \nabla_\nu u^\beta\right] d^4x + \lambda \int \sqrt{-g}(u^2 + 1)\, d^4x + S_{\text{matter}}, \tag{16}$$

where

$$K^{\mu\nu}{}_{\alpha\beta} = c_1 g^{\mu\nu} g_{\alpha\beta} + c_2 \delta^\mu_\alpha \delta^\nu_\beta + c_3 \delta^\mu_\beta \delta^\nu_\alpha + c_4 u^\mu u^\nu g_{\alpha\beta}. \tag{17}$$

Our non-relativistic parameters map to the $c_i$ at leading post-Newtonian order [5].

Current 95% constraints [6, 7]:

- $|c_{13}| = |c_1 + c_3| \lesssim 10^{-15}$ (GW170817 graviton speed)
- $|c_{14}| = |c_1 + c_4| \lesssim 10^{-2}$ (preferred-frame effects)
- $|c_{123}| \lesssim 10^{-1}$ (binary pulsars, stability)

Viable theories are forced into an exquisitely small corner of parameter space extremely close to General Relativity.

# 7 Discussion and Extensions

The pure scalar model cleanly reproduces Newtonian gravity and gravitational redshift but fails every test requiring spatial curvature (light deflection factor 2, perihelion advance, frame-dragging, tensor GWs). The chronometric ontology—time-field first, metric emergent—naturally leads to Einstein-Æther or khronometric theories [8], both heavily constrained.

Promising extensions:

- Emergent metric $g_{ij}^{\text{eff}}(\tau)$ to recover the missing factor of two in light deflection.
- Nonlinear self-interactions of $\tau$ or $u^\mu$ to generate 1PN effects.
- Thermodynamic/entropic origin of the time-field arrow.

Even if no fully viable competitor to General Relativity emerges, the time-first viewpoint provides a novel organising principle for modified gravity.

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