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Phase-Weighted Curvature Effective Field Theory of Gravity from Complex Time-Dilation Structure

Nisarga S
Independent Researcher, Mysore, Karnataka, India

Abstract—**We construct a scalar–tensor effective field theory of gravity derived from a complex phase representation of relativistic time dilation. By expressing time dilation as a complex exponential structure,**

$$d\tau = \mathrm{Re}(d t\, e^{i\theta})$$

the theory naturally generates phase-weighted curvature corrections of the form $\cos(n\theta)$. The resulting covariant effective field theory extends General Relativity while reducing to ΛCDM in the infrared limit. Cosmological perturbations and gravitational wave propagation acquire small corrections constrained by current observational bounds.

I. INTRODUCTION

General Relativity describes gravitational dynamics with high precision, but late-time cosmic acceleration motivates extensions of the theory. Effective field theory provides a controlled framework for incorporating higher-curvature corrections in a consistent manner.

II. FOUNDATIONAL MOTIVATION

Complex Time-Dilation Structure
We begin from the relativistic proper time relation:

$$d\tau = dt \sqrt{(1 - v^2/c^2)}$$

We introduce a phase representation:

$$d\tau = \mathrm{Re}\,(d t\, e^{i\theta(x,t)})$$

Using Euler's relation:

$$e^{i\theta} = \cos\theta + i \sin\theta$$

we obtain:

$$d\tau = dt \cos\theta$$

Thus, physical time emerges as a projection of an underlying complex phase structure.
We further consider cumulative contributions across scales:

$$F_{eff} \sim \Sigma\, T(n) \cos(n\theta)$$

This leads to phase-weighted curvature corrections arising naturally from oscillatory geometric structure.

III. ACTION PRINCIPLE

We define the effective action:

$$S = \int d^4x \sqrt{-g}\, [\, (1/16\pi G) R + \tfrac{1}{2} g^{\mu\nu} \partial_\mu\theta\, \partial_\nu\theta - V(\theta) + \Sigma\, \Lambda_n \cos(n\theta)\,]$$

where R is the Ricci scalar and $\theta(x,t)$ is the scalar phase field.

IV. FIELD EQUATIONS

Einstein equation:

$$G_{\mu\nu} = 8\pi G\, (T_{\mu\nu}^{\theta} + T_{\mu\nu}^{EFT})$$

Scalar field equation:

$$\theta = dV/d\theta - \Sigma\, n\, \Lambda_n \sin(n\theta)$$

V. COSMOLOGY

For a flat FRW universe:

$$ds^2 = -dt^2 + a(t)^2\, d\vec{x}^2$$

Friedmann equation:

$$3H^2 = 8\pi G\rho + \tfrac{1}{2} \theta^2 + V(\theta) + \rho_{EFT}$$

with:

$$\rho_{EFT} = \alpha_1 \cos\theta\, H^2 + \alpha_2 \cos(2\theta)\, \Lambda^2$$

VI. PERTURBATIONS

Scalar perturbations:

$$\nabla^2\Phi = 4\pi G_{eff}\, \delta\rho$$

$$G_{eff} = G\, (1 + \alpha \cos\theta)$$

Tensor perturbations:

$$\ddot{h} + (3H + \nu)\,\dot{h} + (1 + \beta \cos \theta)\, k^2 h = 0$$

VII. OBSERVATIONAL CONSTRAINTS

$$|\alpha| < 10^{-2}, \; |\beta| \ll 1$$

from:
CMB measurements
structure formation
gravitational wave constraints

VIII. LIMITING BEHAVIOR

- $\theta \to 0$: recovery of ΛCDM
- small θ: perturbative GR corrections
- large θ: enhanced curvature effects

IX. CONCLUSION

We construct a scalar–tensor effective field theory of gravity derived from a complex phase representation of time dilation. The oscillatory curvature structure emerges naturally from the real projection of complex exponential dynamics, providing a controlled extension of General Relativity consistent with current observational constraints.