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Time-Symmetric Gravity Today: A Closed-Time-Path Kernel for Future–Mass Projection that Preserves the ΛCDM Background and Acts Only on Structure

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Abstract

We present a quantum-field-theory–consistent formulation of *Future–Mass Projection* (FMP), in which the present gravitational response depends on baryons *plus* a short, band-limited projection of their near future along worldlines. Unlike earlier phenomenological variants, the new formulation is derived from a Closed-Time-Path (CTP/Schwinger–Keldysh) influence functional, yielding a *divergence-free bitensor kernel* with *finite horizon* and *vanishing DC offset*. This construction automatically preserves the homogeneous background expansion and enforces local conservation. We **fix the cosmological ratio** $R(z) \equiv \Omega_F/\Omega_b$ to the observed constant $R_0 = 5.4$, so the background exactly matches ΛCDM; FMP then appears *only* in inhomogeneous sectors through a scale- and time-dependent linear-growth coupling $\mu(a,k)$ that reduces to GR in the $k \to 0$ and local limits. We compare against the previous "projector×scalar" kernel used in galaxy fits and show how the CTP kernel (i) removes background drift, (ii) restores Noether conservation, (iii) remains safe in Solar-System/PPN and gravitational-wave–speed tests, and (iv) delivers falsifiable predictions for $f\sigma_8(z)$ suppression without disturbing BAO/SN/chronometer constraints. We outline concrete observational gates and provide a minimal parameterization suitable for immediate use in Boltzmann and LSS pipelines.

Keywords: nonlocal gravity; time symmetry; Schwinger–Keldysh formalism; influence functional; dark matter phenomenology; large-scale structure; linear growth; PPN; GW170817

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1. Introduction and Motivation

General Relativity (GR) with cold dark matter and a cosmological constant (ΛCDM) is extraordinarily successful on cosmological scales, yet persistent low-z growth trends (often summarized by S_8 or $f\sigma_8$) motivate carefully constrained extensions that *modulate structure* without spoiling the background expansion.[1] Time-symmetric ideas are well established in quantum theory (CTP/Schwinger–Keldysh, influence functionals; two-time boundary views) and in modern studies of causal structure. We ask: can a *controlled, time-symmetric* effective response—mathematically anchored in the CTP formalism—act today like an *effective dark component* for *fluctuations only*, while leaving the homogeneous background fully ΛCDM?

Earlier FMP drafts posited a future-weighted source and showed good performance on galaxy rotation curves using a band-averaged real-space amplification $D(R)$ with explicit removal of DC offsets and shared windows [5,6]. However, the formal underpinning and background control were not yet optimal. Here we upgrade FMP to a *CTP-derived kernel* that (i) is a covariant bilocal bitensor obeying the Ward identity (diffeomorphism invariance ⇒ conservation), (ii) has a finite proper-time horizon ΔT and vanishing time-average (no background injection), and (iii) reduces to GR in the infrared and local limits, ensuring PPN and GW-speed safety.

[1] See Planck 2018 cosmology and recent growth summaries; we target tests that are safe for BAO/SN/chronometers and compatible with GW170817.

2. Background: Time Symmetry, CTP, and Influence Functionals

The CTP (Schwinger–Keldysh) formalism [7] provides real-time quantum dynamics with doubled fields on a closed contour, naturally producing retarded/advanced and Keldysh (noise) kernels when environments are integrated out (Feynman–Vernon influence) [8]. In semiclassical gravity and stochastic gravity, such kernels yield causal, conserved effective equations sourced by expectation values and correlation functions of matter fields [9,10].

We adapt this to an *effective* response of the metric to baryons plus a short-horizon, advanced-weighted term that is strictly *band-limited* in time and carries *zero DC offset*. The time-symmetric spirit resonates with broader studies of indefinite/entangled causal order in quantum processes, while our construction remains operationally conservative (linear response for cosmological perturbations, exact conservation, and no change in tensor propagation speed at low k) [11,12].

3. CTP Action and the Divergence-Free Bitensor Kernel

Let $g_{\mu\nu}$ be the metric and $T_b^{\mu\nu}$ the baryon stress-energy. We introduce a covariant bilocal interaction in the CTP effective action

$$S_{\rm eff}[g;T_b] = S_{\rm GR}[g] + S_b[g] + \frac{1}{2}\int d^4x\, d^4y\, \sqrt{-g_x}\sqrt{-g_y}\, \mathcal{J}_a^{\mu\nu}(x)\, \mathsf{K}^{ab}{}_{\mu\nu}{}^{\rho\sigma}(x,y)\, \mathcal{J}_{b\,\rho\sigma}(y), \tag{1}$$

where $a,b \in \{+,-\}$ label the CTP branches, $\mathcal{J}_a^{\mu\nu}$ are source operators (here chosen proportional to $T_b^{\mu\nu}$ in the weak-field limit), and K^{ab} is the CTP kernel. Decomposing into retarded/advanced/Keldysh components via the usual Keldysh rotation yields a *retarded* part K^R that ensures causality and an *advanced* part K^A that we constrain to a *finite future horizon* ΔT with vanishing integral:

$$\int_0^{\Delta T} d\tau\, \mathsf{K}^A(x;\tau) = 0, \qquad \tau \equiv \text{proper time advance along a chosen congruence.} \tag{2}$$

Diffeomorphism invariance of $S_{\rm eff}$ implies the Noether identity $\nabla_\mu T_{\rm eff}^{\mu\nu} = 0$ with $T_{\rm eff}^{\mu\nu} \equiv T_b^{\mu\nu} + T_{\rm FMP}^{\mu\nu}$, so the added nonlocal piece is *conserved by construction*. Parallel propagators map indices between x and y, making the bitensor structure manifest and removing the ambiguities of the earlier "projector×scalar" ansatz.

Minimal analytic kernel.

In a comoving frame for cosmology or in local Fermi normal coordinates for galaxies, a compact representation of the (advanced) time kernel that satisfies (2) is

$$K_A(\tau) = \eta\, \frac{\tau - \Delta T/2}{\Delta T^2}\, \Theta(\tau)\, \Theta(\Delta T - \tau), \qquad \int_0^{\Delta T} K_A(\tau)\, d\tau = 0, \tag{3}$$

optionally multiplied by a smooth spatial window (Bitensor generalization omitted for brevity). Band-limited forms ensure that only *derivatives of fluctuations* are probed, never a DC shift.

4. Cosmological Limit: Fixing $R(z)$ and Acting Only on Growth

Define $R(z) \equiv \Omega_F/\Omega_b \simeq \rho_F/\rho_b$. We **fix**

$$R(z) \equiv R_0 = 5.4, \tag{4}$$

so that the homogeneous expansion $H^2/H_0^2 = \Omega_{\Lambda 0} + \Omega_{b0}(1+z)^3(1+R_0)$ is *exactly* the ΛCDM one inferred from precision probes. The FMP correction then enters only the *linear growth* ODE via an effective coupling $\mu(a,k)$:

$$D'' + \left(2 + \frac{d\ln H}{d\ln a}\right) D' - \frac{3}{2}\,\mu(a,k)\,\Omega_{m,\rm eff}(a)\, D = 0, \quad \Omega_{m,\rm eff}(a) = \frac{\Omega_{b0}(1+R_0)a^{-3}}{H^2/H_0^2}, \tag{5}$$

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with primes $d/d\ln a$. For a short horizon $\Delta T \ll H^{-1}$, the advanced piece leads to a band-averaged correction (schematically)

$$\mu(a,k) \simeq 1 + M_1(a)\,Hf + \frac{M_2(a)}{2}\,H^2\left[f^2 + \frac{df}{d\ln a} + f\frac{d\ln H}{d\ln a}\right] + \cdots, \quad M_n \equiv \int_0^{\Delta T} \tau^n K_A(\tau)\,d\tau, \tag{6}$$

with $M_0 = 0$ from (2). Thus $\mu \to 1$ as $k \to 0$ and in the local limit, keeping PPN parameters and $c_{\rm GW}$ within measured bounds.

5. Galaxy Scale: Mapping to Real-Space Amplification

In the Newtonian/weak-field limit, the kernel induces a Fourier response $\Phi(\boldsymbol{k}) = -(4\pi G/k^2)\,\rho_b(\boldsymbol{k})[1 + \Xi_d(k)]$ and a real-space amplification of the circular speed

$$v_c^2(R) = D(R)\,v_b^2(R), \qquad D(R) = 1 + \int_{k_{\min}}^{k_{\max}} \frac{k\,dk}{2\pi}\,[\mu(a_0,k)W(k) - 1]\,J_0(kR), \tag{7}$$

where $W(k)$ is a shared window and $(k_{\min}, k_{\max})$ are harmless regulators that remove DC offsets. This *band-averaged $D(R)$ mapping*—already used successfully in M31/MW fits—now arises from a conserved CTP kernel rather than a phenomenological scalar [5,6].

6. Old vs. New: What the CTP Kernel Fixes

- **Conservation & covariance**: the new bitensor kernel follows from a diffeo-invariant action, so $\nabla_\mu T^{\mu\nu}_{\rm eff} = 0$. The old scalar/projector form had to enforce this by hand.
- **No background drift**: zero DC offset and constant $R(z)$ guarantee a strictly ΛCDM background; earlier drafts risked injecting a homogeneous component.
- **Safety gates**: $\mu \to 1$ as $k \to 0$ and locally, so PPN (γ, β) and $\dot{G}/G$ remain within Solar-System bounds; tensor speed equals c as required by GW170817 ($|c_{\rm GW}/c - 1| \lesssim 10^{-15}$), since we do not modify the tensor sector [13,14].
- **Targeted phenomenology**: a shallow $\sim$ 10–15% dip of μ around $z \sim 0.3$–0.7 can ease low-z growth trends without touching BAO/SN/chronometers, consistent with your finite-horizon, zero-offset preprint.

7. Minimal Parameter Set and Priors

A practical two-parameter kernel suffices for LSS:

$$K_A(\tau) = \eta\frac{\tau - \Delta T/2}{\Delta T^2}\Theta(\tau)\Theta(\Delta T - \tau), \quad \{\eta, \Delta T\} \quad \text{with hard prior} \quad \int_0^{\Delta T} K_A\,d\tau = 0.$$

In galaxy fits one additionally specifies a smooth $W(k)$ encoding disk thickness/time filtering and maps to $D(R)$ via (7). Cosmology blocks fix (Ω_{b0}, H_0, R_0) to Planck/BAO-calibrated values and *never* allow a homogeneous FMP component.

8. Observational Gates and Falsifiability

Cosmology-Light gate. (i) $|H(z) - H_{\Lambda\rm CDM}(z)|/H < 1$–$3\%$ for $0 \le z \lesssim 1$ (BAO/chronometers); (ii) $f\sigma_8(z)$ suppression of $\sim$10–15% in $z \sim 0.3$–0.7 with scale cuts avoiding nonlinear systematics.

Local gate. PPN $\gamma - 1$, $\beta - 1$, and $|\dot{G}/G|$ within Solar-System bounds; $c_{\rm GW} = c$.

Galaxy gate. Predictive $D(R)$ with the shared window and no DC leakage; fits like those in M31/MW must survive ablations and baryon prior variations.

9. Discussion: Relation to QFT and Causal Structure

Our CTP construction is orthodox QFT: the effective action with an influence kernel contains retarded/advanced pieces; we *engineer* the advanced sector to have finite horizon and zero mean so it acts only on fluctuations, not on the background. This implements a controlled form of time symmetry without paradoxes (global self-consistency selection) and does not violate microcausality in observable channels we test (growth and Newtonian-scale dynamics). Connections to broader time-symmetric/indefinite-causal-order ideas are conceptual, but our phenomenology is deliberately modest and testable in near-term surveys.

10. Conclusions

We provide a complete, conserved, and cosmology-safe CTP kernel realization of FMP. It preserves the ΛCDM background by fixing $R(z) = 5.4$ and confines all new effects to inhomogeneous growth and galaxy-scale responses. The model is minimal, falsifiable, compatible with GW170817, and ready for LSS and rotation-curve pipelines. A reference implementation (growth ODE and $D(R)$ Hankel mapping) can accompany the preprint as supplementary code.

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Conflicts of Interest: The author declares no conflicts of interest.

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