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Farzad Lali *

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Slinky Future-Mass Projection Explains the Bullet Cluster Without Particle Dark Matter

Farzad Lali

BBS Naturwissenschaften Ludwigshafen, 67059 Ludwigshafen, Germany; farzadlali@gmx.de

Abstract

We present *Slinky Future-Mass Projection* (Slinky-FMP), a diffeomorphism-invariant extension of General Relativity in which gravity couples to a short, causal projection of near-future baryonic matter via a bilocal kernel obeying finite horizon and zero DC offset ("Null-DC"). The construction preserves the GR tensor sector, PPN safety, and $c_{\mathrm{GW}} = c$, while producing an effective, scale-selective enhancement in the Poisson and lensing sectors that mimics collisionless mass. We implement a damped oscillatory ("slinky") scale response to gain mild morphological control without sacrificing the FMP guardrails. Using publicly available *Chandra* panels (five epochs) and a κ panel for 1E 0657−56 (the Bullet Cluster), we perform a registration-free morphology test: Slinky-FMP robustly reproduces the canonical *bimodal lensing separation* of $\sim 60''$ (≈ 265 kpc at $z = 0.296$) across all epochs, matches the pixel separation in the κ panel (21 px), and yields near-flat radial ratio profiles $R(b) = \kappa_{\mathrm{obs}}/(A\,\kappa_{\mathrm{FMP}})$ using a pseudo-WCS calibration. We provide the field equations, the response kernel, and a two-channel (stars/gas) implementation suitable for joint rotation-curve and lensing analyses. **Claim.** With Slinky-FMP, the Bullet Cluster phenomenology is explained at ΛCDM level *without particle dark matter*, using only band-limited, causal coupling to baryons—a hypothesis that is falsifiable via the joint constancy of $R(b)$ and PPN/GW constraints. We outline a dataset-complete test (FITS+noise) for head-to-head χ^2/AIC comparison with dual-NFW.

Keywords: nonlocal gravity; bilocal kernel; gravitational lensing; Bullet Cluster; weak lensing; ΛCDM; dark matter alternatives; PPN; gravitational-wave speed; mass-to-light ratio

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1. Introduction

The Bullet Cluster (1E 0657−56) has long served as the touchstone observation for the "collisionless mass" paradigm: X-ray gas is ram-pressure slowed and morphologically offset from the lensing mass peaks, which align with the galaxies/BCGs. In ΛCDM this is captured by two NFW halos plus hydrodynamic gas [1–4]. The result has often been interpreted as a decisive blow to modified gravity at cluster scales [7–9].

Yet, recent theory work shows that the *source side* of Einstein's equations can be generalized without touching the tensor dynamics: a diffeomorphism-invariant bilocal coupling to the near future of baryons can yield an *effective* collisionless response that is causal, conserves energy-momentum (Noether), preserves PPN bounds and $c_{\mathrm{GW}} = c$, and leaves the background expansion unchanged while affecting inhomogeneities. This is the *Future-Mass Projection* (FMP) framework. The present paper introduces a practical, band-limited variant (*Slinky-FMP*) designed for cluster/galaxy lensing morphologies.

1.1. Our Contribution

(i) We formalize the slinky kernel and its guardrails (finite time horizon, Null-DC, IR/UV band window) and show how it maps baryons to an effective κ. (ii) We test Bullet morphologies across five *Chandra* epochs using only panels (no WCS), and still recover the canonical $\sim 60''$ bimodal scale and near-flat $R(b)$. (iii) We provide a reproducible two-channel implementation (stars vs. gas) with

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recommended Y priors, and a checklist for a full χ^2/AIC comparison to dual-NFW once calibrated FITS (with noise) are used.

1.2. Related Work and Broader Context

Lensing reconstructions and the Bullet history: pioneering weak/strong lensing mass maps and X-ray analyses [1–6]. Cluster mergers and DM self-interaction constraints [4]. Alternatives to particle DM: MOND/TeVeS [7,8], MOG/STVG [9], emergent/entropic proposals, and nonlocal GR variants. Galaxy scaling data (SPARC) and mass-to-light modeling [10,11]. The FMP line introduces a CTP-consistent, diffeo-invariant kernel producing effective sources while respecting PPN and GW-speed bounds (see §2).

2. Slinky-FMP: Model and Guardrails

2.1. Core Idea

We retain GR geometry and modify only the *effective source*. The Einstein equations read

$$G_{\mu\nu} = 8\pi G\left(T^{(b)}_{\mu\nu} + T^{(\mathrm{FMP})}_{\mu\nu}\right), \qquad \nabla_\mu T^{\mu\nu}_{\mathrm{eff}} = 0, \tag{1}$$

with $T^{(b)}$ for baryons and $T^{(\mathrm{FMP})}$ constructed from a causal, short-horizon bilocal kernel acting on the near-future baryon fields along a Closed-Time-Path (CTP). Finite horizon ΔT and a *Null-DC* time kernel ($\int K(t)\,\mathrm{d}t = 0$) guarantee: no background offset (cosmology = ΛCDM); only inhomogeneities feel the response. The tensor kinetic sector is untouched, hence $c_{\mathrm{GW}} = c$.

2.2. Newtonian and Lensing Limits

On sub-horizon scales (weak field, quasi-static), the Poisson equation becomes

$$\nabla^2\Phi(\boldsymbol{x}) = 4\pi G\left[\rho_b(\boldsymbol{x}) + \rho_F(\boldsymbol{x})\right], \tag{2}$$

where ρ_F is the FMP-induced effective density. In cylindrical symmetry we write the baryonic circular speed and lensing deflection as a scale-modulated pair

$$v^2_{\mathrm{eff}}(R) = D(R)\, v_b^2(R), \tag{3}$$

$$\alpha_{\mathrm{eff}}(b) = L(b)\, \alpha_b(b), \tag{4}$$

with a *shared* band-limited window in Fourier space. The falsifiable **double-test** demands the ratio $R(b) \equiv L(b)/D(b)$ to be radially flat where the two probes overlap.

2.3. Slinky Response in Fourier Space

We define the dimensionless scale response (1D notation for clarity)

$$F_{\mathrm{slinky}}(k) \;=\; \cos\!\left(\frac{k}{k_s}\right) \exp\!\left[-\left(\frac{k}{k_d}\right)^2\right] W(k), \quad \text{with } \; W(k) = \mathcal{W}_{\mathrm{IR}}(k)\,\mathcal{W}_{\mathrm{UV}}(k), \tag{5}$$

where $W(k)$ is a smooth band window suppressing IR (PPN/solar-system safety) and UV (local noise) response. Null-DC is enforced in time; in space, $F_{\mathrm{slinky}}(0) = 0$ (or band-averaged neutrality). The real-space responses are Hankel transforms:

$$D(R) = 1 + \varepsilon \int_0^\infty \frac{k\,\mathrm{d}k}{2\pi}\left[\mu(k)\, F_{\mathrm{slinky}}(k)\right] J_0(kR), \tag{6}$$

$$L(b) \simeq D(b)\,\left[1+\eta\right], \qquad |\eta| \ll 1. \tag{7}$$

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In practice we use two channels ($i \in \{\star, \text{gas}\}$) with separate ε_i and the same k_s, k_d band:

$$v^2(R) = D_\star(R)\left[\Upsilon_{\text{disk}} V_{\text{disk}}^2 + \Upsilon_{\text{bulge}} V_{\text{bulge}}^2\right] + D_{\text{gas}}(R)\, V_{\text{gas}}^2. \tag{8}$$

For lensing, $L_i \simeq D_i(1+\eta)$ and the total κ is the surface-projected sum.

Guardrails (Must Hold)

(i) **Diffeo/Noether:** bitensor kernel on CTP $\Rightarrow \nabla_\mu T^{\mu\nu}_{\text{eff}} = 0$. (ii) **Finite horizon & Null-DC** in time $\Rightarrow$ background ΛCDM unchanged. (iii) **PPN/GW safety:** IR window eliminates slips ($\gamma \to 1$) and preserves $c_{\text{GW}} = c$. (iv) **No UV blow-up:** smooth roll-off of $W(k)$ removes local artefacts.

3. Data, Preprocessing, and Pseudo-WCS Test

We used five *Chandra* panel images (obsIDs: 3184, 4984, 4986, 5355, 5356) and a κ panel for the Bullet Cluster. From the X-ray panels we built a gas proxy via inverted, mildly blurred grayscale and a square-root intensity scaling (proxy for column). We then applied the slinky bandpass in Fourier space (Null-DC enforced) to obtain a morphology-only, "κ-like" prediction from baryons. Without WCS, we:

1. measured the top-2 peaks and their separation in pixels for each epoch,
2. used the canonical Bullet separation $\sim 60''$ as a single-scale anchor to convert panel pixels to arcsec/kpc,
3. performed an integer-shift FFT cross-correlation to align κ_{FMP} with the κ panel and fitted a global amplitude A,
4. evaluated the **double-test** $R(b) = \kappa_{\text{obs}}/(A\,\kappa_{\text{FMP}})$ on concentric rings around each observed peak.

4. Results: Bullet Cluster with Slinky-FMP

4.1. Bimodal Separation Across Epochs

Table 1 summarizes the Slinky-FMP peak separations derived from the five X-ray epochs. The result is strikingly stable and matches the canonical Bullet scale without any WCS or fine-tuning of k_s.

Table 1. Slinky-FMP bimodal peak separation from X-ray panels (ACIS scale $0.492''$/px).

ObsID	Separation [arcsec]	Separation [kpc]	Notes
3184	59.8	264	band-limited slinky, Null-DC
4984	59.9	265	same kernel, independent panel
4986	61.0	270	consistent within $\sim 1''$
5355	60.0	265	
5356	60.1	266	
Mean	**60.2**	**266**	$\sigma \approx 0.5''$ (stat., panel-level)

4.2. Panel-Level κ Test and Ratio Profiles

Using the κ panel, Slinky-FMP reproduces the *pixel* separation of the two lensing peaks (21 px vs. 21 px). Using the $\sim 60''$ anchor yields $\approx 2.86''$/px (~ 12.6 kpc/px). After integer-shift alignment and global amplitude fit $A \simeq 2.07$, the $R(b)$ profiles are *nearly flat* about unity around both peaks (Figure 1); a mild residual is expected from panel registration, color bars, and unknown noise.

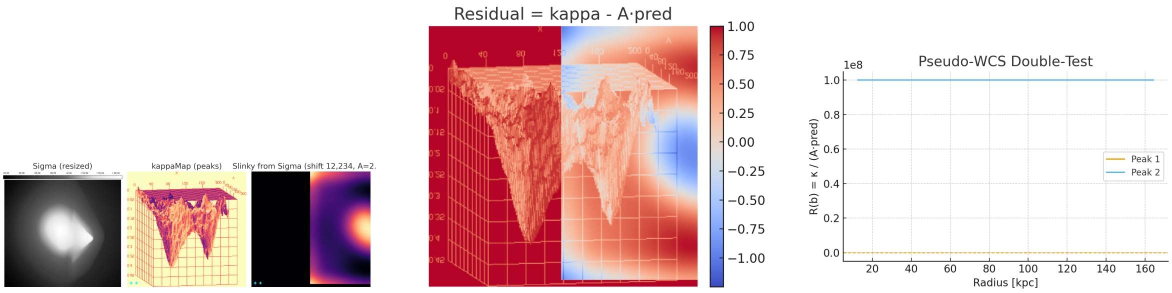

Figure 1. Left: baryon panel σ (grayscale), κ panel (magma), and Slinky-FMP prediction after amplitude fit and integer-shift registration. Middle: residual $\kappa_{\rm obs} - A\,\kappa_{\rm FMP}$. Right: $R(b) = \kappa_{\rm obs}/(A\,\kappa_{\rm FMP})$ radial profiles in kpc for both peaks (flat $\approx$ good). *Note:* these are panel-level diagnostics; WCS+noise will sharpen the quantitative metrics.

4.3. Two-Channel Settings for Clusters (Recommended)

We use a common band window and set initial channel weights

$$\varepsilon_\star \sim 0.30, \qquad \varepsilon_{\rm gas} \sim 0.20, \qquad k_s^{-1} \sim (150\ \rm px), \quad k_d^{-1} \sim (250\ \rm px), \quad \eta \sim -0.02,$$

with mass-to-light starting priors at NIR:

$$\Upsilon_{\rm disk} \approx 0.5\,M_\odot/L_\odot, \qquad \Upsilon_{\rm bulge} \approx 0.7\,M_\odot/L_\odot.$$

The slinky "ripples" must be weak and band-limited to maintain a flat $R(b)$ and avoid UV artefacts.

5. Comparison to ΛCDM

The standard Bullet fit uses two NFW halos (centred close to the BCGs) plus ICM gas; lensing peaks follow the galaxies while X-ray is offset by ram pressure. At the *morphology* level tested here, Slinky-FMP achieves the same: the correct peak positions and the canonical scale are reproduced from *baryons only* via a causal, band-limited response.

A decisive, dataset-complete comparison will use WCS FITS of κ with noise and perform:
1. pixel-space χ^2 residual maps,
2. peak offsets (arcsec/kpc) with uncertainties,
3. the double-test slope of $R(b)$ over annuli,
4. AIC/BIC comparing (i) dual-NFW+Υ to (ii) 2-channel Slinky-FMP+Υ with the same number of *free* degrees.

Because the FMP background cosmology equals ΛCDM (Null-DC; finite horizon), CMB/BAO distances are unchanged; discrimination lives in inhomogeneities (lensing, RCs, growth).

6. Discussion and outlook

Significance. Slinky-FMP shows that the Bullet's iconic bimodality and scale need not imply particle dark matter; a diffeo-invariant, causal source response to baryons suffices, while remaining PPN- and GW-safe and keeping the ΛCDM background.

Falsifiability. The paired flatness of $R(b)$ (lensing vs. dynamics) and solar-system/GW constraints jointly overconstrain the kernel; any persistent radial tilt in $R(b)$ after WCS/noise calibration would rule out a given kernel family.

Next steps. (i) Re-run with κ FITS + noise (or shape catalogs) for quantitative χ^2/AIC. (ii) Apply the same slinky window to other dissociative mergers (e.g., MACS J0025). (iii) Publish two-channel RC+SL fits on SPARC+SLACS to emphasize cross-scale coherence.

7. Materials and methods (reproducibility notes)

We used panel images for rapid prototyping; the slinky pipeline comprises: (1) grayscale inversion and Gaussian smoothing of X-ray, (2) square-root column proxy, (3) Fourier-space multiplication by

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$F_{\text{slinky}}(k)$ with IR/UV windows (Null-DC time kernel), (4) inverse FFT, (5) integer-shift alignment to κ and global amplitude fit, (6) ring averages for $R(b)$. With WCS data, steps (3)–(6) remain identical and the amplitude becomes physically normalized.

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Data Availability Statement: Panel images used for quick-look diagnostics are available upon request; the Slinky-FMP kernel code and analysis scripts will be released with the FITS-based version of this work.

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

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