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Posted Date: 27 November 2025

doi: 10.20944/preprints202511.2202.v1

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Article

Reinterpreting the Fermi Gamma-Ray Halo of the Milky Way in Terms of Future-Mass Projection Gravity

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Abstract

A recent analysis of fifteen years of *Fermi*–LAT data reports a statistically significant, approximately spherical gamma-ray halo around the Milky Way, with a spectrum that peaks near $E_\gamma \sim 20$ GeV and a morphology well fitted by the square of a smooth Navarro–Frenk–White (NFW) density profile. Interpreted as annihilation of weakly interacting massive particles (WIMPs) into $b\bar{b}$, the corresponding cross section is $\langle\sigma v\rangle \sim (5\text{--}8) \times 10^{-25} \text{ cm}^3 \text{ s}^{-1}$, which exceeds the canonical thermal relic value and lies in tension with bounds from dwarf spheroidal galaxies and the extragalactic gamma-ray background. In this work, the same halo is reinterpreted within the Future–Mass Projection (FMP) framework, a diffeomorphism–invariant bilocal modification of gravity defined on a closed time path. In the Newtonian limit, FMP produces an effective “future–mass” density ρ_F sourced nonlocally by baryons, such that the Poisson equation becomes $\nabla^2\Phi = 4\pi G(\rho_b + \rho_F)$. The *Fermi* halo is then naturally identified with ρ_F of the Milky Way, and its NFW parameters calibrate the FMP kernel for our Galaxy. We show that the required kernel parameters (ε, k_0) fall in the same range previously inferred from SPARC rotation curves, cluster lensing (including the Bullet Cluster), and cosmological background evolution. In this picture the 20 GeV gamma-ray excess constrains cosmic-ray emission and transport in the FMP–modified potential, while the WIMP interpretation becomes at best an upper limit on any genuine nonbaryonic component.

Keywords: dark matter; gamma rays; Milky Way halo; modified gravity; nonlocal gravity; Future–Mass Projection; Fermi–LAT

1. Introduction

The standard Λ CDM model describes the cosmic microwave background (CMB), large-scale structure, and the expansion history of the Universe with impressive precision, provided that most of the matter content is a cold, collisionless dark component. On galactic scales, however, the phenomenology is often more directly captured by empirical relations between baryons and kinematics, such as the baryonic Tully–Fisher relation, than by explicit halo models. This tension has motivated both particle–dark–matter scenarios and modifications of gravity or inertia.

In the particle picture, weakly interacting massive particles (WIMPs) are among the best studied candidates. Their thermal freeze–out naturally yields relic abundances of the right order, and their annihilation or decay could produce detectable gamma rays, cosmic rays, or neutrinos in regions of high dark–matter density such as the Galactic Centre, dwarf spheroidal galaxies, or galaxy clusters [1–3]. After years of dedicated searches, no unambiguous spectral lines or morphology uniquely attributable to WIMPs have been found. Limits from dwarf spheroidals and the isotropic gamma-ray background strongly disfavour the simplest s–wave annihilation channels in the mass range from a few GeV to several TeV [4–6].

An alternative is to modify dynamics rather than invoke new particles. The original Modified Newtonian Dynamics (MOND) proposal [7–9] introduces an acceleration scale a_0 below which the

effective gravitational law departs from Newton, thereby explaining the Tully–Fisher relation and many rotation curves with minimal free parameters. However, cluster mass profiles, cosmological structure formation, and gravitational lensing remain difficult to reconcile with a purely local MOND prescription [10–12]. Relativistic completions such as TeVeS [13] or bimetric and scalar–tensor theories add additional fields and complexities, and often still require some amount of unseen matter.

A third line of research considers nonlocal or bilocal extensions of general relativity, in which the Einstein tensor at x depends on an integral over the energy–momentum tensor at other points x' through a kernel $K(x, x')$ [14–16]. Such kernels can arise as effective descriptions of quantum loops in curved spacetime, coarse–grained backreaction from inhomogeneities, or integrating out microscopic degrees of freedom. In their simplest cosmological incarnations they can mimic dark energy; with more structure they can also generate effective dark–matter–like behaviour.

The Future–Mass Projection (FMP) framework belongs to this latter class. It introduces a diffeomorphism–invariant bilocal kernel defined on a closed time path (CTP) contour and couples the Einstein tensor to an integral over the baryonic energy–momentum tensor along this contour [17,18]. The kernel is constrained by general covariance, CTP symmetry, and conservation of the total Noether charge. In the Newtonian limit this leads to a modified Poisson equation in which the source density is the sum of the local baryon density ρ_b and a nonlocal “future–mass” density ρ_F induced by the kernel. At the cosmological level, renormalization of the kernel yields a constant ratio

$$R_0 \equiv \frac{\Omega_F}{\Omega_b} \simeq 5.4, \quad (1)$$

reproducing the effective dark–to–baryon ratio of Λ CDM without introducing new particles [19].

On galactic and cluster scales, the same kernel can be parametrised by an amplitude ε and a characteristic wavenumber k_0 . In Fourier space one finds

$$\Phi_{\text{eff}}(\mathbf{k}) = [1 + \varepsilon F(k)] \Phi_b(\mathbf{k}), \quad F(k) = \frac{1}{1 + (k/k_0)^2}, \quad (2)$$

where Φ_b is the baryonic Newtonian potential and $F(k)$ is a Lorentzian form factor induced by the bilocal kernel [22]. In real space this behaves roughly like a Yukawa–type kernel with range $L_0 \sim k_0^{-1}$: local gravity is dominated by baryons, while at scales $r \gtrsim L_0$ an extended halo–like component appears. The same kernel modifies both rotation curves,

$$v_{\text{eff}}^2(R) = D(R) v_b^2(R), \quad D(R) = 1 + \varepsilon F(1/R), \quad (3)$$

and gravitational lensing, where the deflection angle is amplified by a factor $1 + \eta \varepsilon F(1/b)$ with $\eta \sim 1$ and impact parameter b [21,23].

Using this minimal parametrisation, FMP has been shown to fit a large sample of galaxies from the SPARC database [24] with a single pair (ε, k_0) , and to reproduce the lensing mass distribution of the Bullet Cluster and similar systems without particle dark matter [21,22]. The same parameter range is also consistent with solar–system post–Newtonian constraints and the speed of gravitational waves [23].

Recently, Totani [25] analysed fifteen years of *Fermi*–LAT data, focusing on a halo region $|l| \leq 60^\circ$, $10^\circ \leq |b| \leq 60^\circ$, and reported a statistically significant “Fermi halo”: a smooth, approximately spherical excess of diffuse gamma–ray emission peaking at $E_\gamma \sim 20$ GeV. After subtracting point sources, gas–correlated emission, inverse Compton components from GALPROP, Loop I, the Fermi Bubbles, and an isotropic template, the residual is well fitted by the square of an NFW density profile with scale radius $r_s \simeq 21$ kpc and local density $\rho_\odot \sim 0.4$ GeV cm $^{-3}$. If interpreted as annihilation of WIMPs into $b\bar{b}$, the best–fit parameters are $m_\chi \simeq 0.5$ – 0.8 TeV and $\langle\sigma v\rangle \sim (5$ – $8) \times 10^{-25}$ cm 3 s $^{-1}$, which overshoot the canonical thermal cross section and are in tension with dwarf–galaxy limits, although

the author argues that astrophysical and profile uncertainties may still leave room for a dark-matter interpretation [25].

From the perspective of FMP, this result is naturally reframed. The *Fermi* analysis measures an effective smooth halo around the Milky Way whose morphology follows an NFW-like profile; in FMP such a halo arises automatically as the future-mass density ρ_F sourced by baryons through the nonlocal kernel. Instead of inferring a large annihilation cross section for a new particle species, one can treat the NFW parameters inferred from gamma rays as constraints on (ε, k_0) for the Milky Way. The 20 GeV excess then constrains baryonic cosmic-ray emission and transport in this potential, and indeed limits any residual WIMP component.

The purpose of this paper is to make this connection explicit. In Sec. 2 we briefly review the Newtonian limit of FMP and the Lorentzian kernel parametrisation. In Sec. 3 we summarise the salient features of Totani's analysis. In Sec. 4 we map the inferred NFW halo onto FMP kernel parameters for the Milky Way and compare them to the values required by SPARC galaxies and cluster lensing. In Sec. 5 we discuss the interpretation of the 20 GeV bump as baryonic cosmic-ray emission in an FMP potential, and the status of WIMP annihilation as an upper limit. We conclude in Sec. 6.

2. Overview of Future-Mass Projection Gravity

In FMP gravity the Einstein equations are generalised to a bilocal relation

$$G_{\mu\nu}(x) = 8\pi G \int d^4x' K_{\mu\nu}{}^{\alpha\beta}(x, x') T_{\alpha\beta}(x'), \quad (4)$$

where $K_{\mu\nu}{}^{\alpha\beta}(x, x')$ is a causal kernel defined on a closed time path and $T_{\alpha\beta}$ is the baryonic energy-momentum tensor [17,18]. The kernel is constructed to satisfy:

- diffeomorphism invariance, such that $\nabla^\mu G_{\mu\nu} = 0$ implies a corresponding nonlocal conservation law for the CTP charge,
- CTP symmetry between incoming and outgoing branches,
- PPN safety in the weak-field, slow-motion regime,
- a finite temporal horizon, reflecting a renormalised kernel with zero offset [20].

In the Newtonian and quasistatic limit, the metric can be written as

$$ds^2 = -(1 + 2\Phi) dt^2 + (1 - 2\Phi) dx^2, \quad (5)$$

and Eq. (4) reduces to a modified Poisson equation,

$$\nabla^2 \Phi(x) = 4\pi G [\rho_b(x) + \rho_F(x)], \quad (6)$$

where ρ_b is the local baryonic mass density and ρ_F is a nonlocal contribution from the kernel,

$$\rho_F(x) = \int d^3x' K_N(x, x') \rho_b(x'), \quad (7)$$

with K_N the Newtonian limit of $K_{\mu\nu}{}^{\alpha\beta}$. The combination $\rho_b + \rho_F$ is what would be inferred as “total mass” in a Newtonian analysis of dynamics or lensing.

In Fourier space, Eq. (6) takes the form

$$\Phi_{\text{eff}}(\mathbf{k}) = \frac{-4\pi G}{k^2} [\rho_b(\mathbf{k}) + \rho_F(\mathbf{k})] = \frac{-4\pi G}{k^2} [1 + \varepsilon F(k)] \rho_b(\mathbf{k}), \quad (8)$$

where the second equality defines the dimensionless kernel amplitude ε and form factor $F(k)$. The minimal phenomenological choice consistent with the CTP construction and a finite horizon is the Lorentzian form in Eq. (2),

$$F(k) = \frac{1}{1 + (k/k_0)^2}, \quad (9)$$

with characteristic wavenumber k_0 and range $L_0 \equiv k_0^{-1}$.

This form factor leads to an effective dynamical amplification factor

$$D(R) \equiv \frac{v_{\text{eff}}^2(R)}{v_b^2(R)} = 1 + \varepsilon F(1/R), \quad (10)$$

for circular velocities at radius R . At small radii, $R \ll L_0$, one has $F(1/R) \rightarrow 1$ and $D \rightarrow 1 + \varepsilon$, corresponding to a roughly isothermal halo. At large radii, $R \gg L_0$, $F(1/R) \rightarrow (R/L_0)^2$ and the effective halo contribution decays.

The same kernel modifies gravitational lensing. In the thin-lens approximation the deflection angle for a light ray with impact parameter b is amplified by

$$\alpha_{\text{eff}}(b) = [1 + \eta \varepsilon F(1/b)] \alpha_b(b), \quad (11)$$

where η is an order-unity factor depending on the details of the kernel contraction in the null-geodesic limit [21,23].

On cosmological scales, averaging Eq. (4) over large volumes and renormalising the kernel yields a homogeneous future-mass density ρ_F whose ratio to the baryonic density ρ_b is constant in time [19],

$$R(z) \equiv \frac{\Omega_F(z)}{\Omega_b(z)} = R_0 \simeq 5.4. \quad (12)$$

This reproduces the effective dark-matter density of Λ CDM in the background Friedmann equations and in linear perturbations, while the nonlocal kernel handles the halo-like phenomenology on smaller scales.

Fits to SPARC rotation curves and cluster lensing indicate a preferred range

$$\varepsilon \sim \mathcal{O}(1-3), \quad L_0 \sim \mathcal{O}(5-20 \text{ kpc}), \quad (13)$$

with modest scatter between galaxies of different mass and surface density [21,22]. In the following we will see that the Milky Way parameters implied by the *Fermi* halo are consistent with this range.

3. Summary of the Fermi Halo Analysis

Totani [25] analysed 15 years of *Fermi* Large Area Telescope (LAT) data with the aim of searching for gamma rays from dark-matter annihilation in the Milky Way halo. The region of interest (ROI) is defined by Galactic longitudes $|l| \leq 60^\circ$ and latitudes $10^\circ \leq |b| \leq 60^\circ$, excluding the bright Galactic plane. The photon energy range is 1.5–810 GeV, and the UltraClean event class is used to minimise charged-particle contamination.

The observed intensity map in the ROI is modelled as a linear combination of:

- point-source templates from the 4FGL catalogue,
- gas-correlated emission components from GALPROP (neutral and ionised gas, π^0 decay),
- inverse Compton scattering (ICS) templates for different interstellar radiation fields,
- large-scale diffuse structures: Loop I and the Fermi Bubbles,
- an isotropic background component.

The parameters of these templates are determined by a binned Poisson likelihood fit. To enhance sensitivity to smooth structures on halo scales, the fit is performed using cell sizes of order $10^\circ \times 10^\circ$, rather than pixel-by-pixel.

After subtracting the best-fit combination of templates from the data, a residual component remains that:

- is locally consistent with zero for $E_\gamma \lesssim 2 \text{ GeV}$ and $E_\gamma \gtrsim 200 \text{ GeV}$,
- shows a broad excess peaking at $E_\gamma \sim 20 \text{ GeV}$,
- exhibits an approximately spherical morphology centred on the Galactic Centre,

- is well fitted by a spherically symmetric halo template with emissivity proportional to $\rho_{\text{NFW}}^2(r)$, where

$$\rho_{\text{NFW}}(r) = \frac{\rho_s}{x(1+x)^2}, \quad x = \frac{r}{r_s}, \quad (14)$$

with best-fit scale radius $r_s \simeq 21$ kpc and local density $\rho_\odot \approx 0.42 \text{ GeV cm}^{-3}$ for a solar radius $R_\odot \simeq 8$ kpc.

The radial profile is slightly shallower than a pure NFW² cusp in the innermost region, and can also be described by an Einasto profile with a modest core.

Systematic uncertainties are probed by:

- varying the GALPROP parameters (halo height, source distribution, diffusion coefficients),
- changing the Fermi Bubble templates (different energy bands or morphologies),
- masking bright point sources instead of fitting them,
- using the official LAT Galactic interstellar emission model (GIEM) as an alternative background, which includes non-template patches tuned to match observed residuals.

In all these tests, the qualitative behaviour of the residual halo persists: it rises from ~ 1 GeV, peaks around 20 GeV, and becomes negligible above 200 GeV. In particular, a similar excess is found even relative to the GIEM, suggesting that the signal is not an artefact of template construction [25].

If the halo residual is interpreted as gamma rays from WIMP annihilation into $b\bar{b}$, the best-fit parameters are

$$m_\chi \sim 0.5\text{--}0.8 \text{ TeV}, \quad \langle\sigma v\rangle \sim (5\text{--}8) \times 10^{-25} \text{ cm}^3 \text{ s}^{-1}, \quad (15)$$

for a standard NFW profile normalised to $\rho_\odot \simeq 0.4 \text{ GeV cm}^{-3}$. The corresponding cross section is:

- more than an order of magnitude larger than the canonical thermal relic value $\sim (2\text{--}3) \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$,
- several times larger than the 95% confidence upper limits derived from dwarf spheroidal galaxies [4],
- comparable to or slightly above bounds from the Galactic halo in earlier studies [5].

Totani emphasises that this tension does not provide a definitive exclusion, given uncertainties in the Milky Way halo profile, substructure, and dwarf-galaxy mass modelling, but cautions that independent confirmation is required before claiming a discovery of dark matter [25].

For our purposes, the central output of Ref. [25] is the effective NFW halo profile and its parameters (r_s, ρ_s) , derived from gamma-ray data, which can be reinterpreted as an FMP future-mass distribution.

4. Mapping the Fermi Halo to FMP Kernel Parameters

In the FMP framework, what is traditionally called “dark matter halo” is replaced by the future-mass density $\rho_F(x)$ induced by the bilocal kernel acting on baryons. For a given baryonic mass distribution $\rho_b(x)$, the nonlocal term in Eq. (6) generates a smooth extended halo whose detailed shape depends on (ε, k_0) .

In practice, phenomenological analyses can proceed in either of two equivalent ways:

- starting from a given baryon model, compute Φ_{eff} using Eq. (2) and fit (ε, k_0) directly to observational data (rotation curves, lensing, etc.), or
- infer an effective halo profile (e.g. NFW) from data using standard Newtonian techniques, and then ask which (ε, k_0) would reproduce the same dynamical effects in FMP.

Here we adopt the second approach, using Totani’s inferred NFW halo as a constraint on (ε, k_0) for the Milky Way.

4.1. Effective mass profile of the Milky Way halo

The NFW parameters (r_s, ρ_s) inferred in Ref. [25] correspond to a halo profile

$$\rho_F(r) = \frac{\rho_s}{\frac{r}{r_s} \left(1 + \frac{r}{r_s}\right)^2}, \quad (16)$$

with $r_s \simeq 21$ kpc and local density $\rho_\odot \approx 0.42 \text{ GeV cm}^{-3}$ at $R_\odot \simeq 8$ kpc. The corresponding enclosed mass is

$$M_F(< r) = 4\pi\rho_s r_s^3 \left[\ln\left(1 + \frac{r}{r_s}\right) - \frac{r/r_s}{1 + r/r_s} \right]. \quad (17)$$

For $r \sim 8\text{--}50$ kpc, typical values are $M_F(< 8 \text{ kpc}) \sim 4 \times 10^{10} M_\odot$ and $M_F(< 50 \text{ kpc}) \sim 5 \times 10^{11} M_\odot$, comparable to standard Milky Way halo models.

Let $v_{\text{obs}}(R)$ denote the observed circular velocity profile of the Milky Way and $v_b(R)$ the contribution from baryons (disk + bulge + gas) computed from an independent mass model. At $R_\odot$, a representative estimate is

$$v_{\text{obs}}(R_\odot) \approx 230 \text{ km s}^{-1}, \quad v_b(R_\odot) \approx 150 \text{ km s}^{-1}, \quad (18)$$

implying a dynamical amplification factor

$$D(R_\odot) \equiv \frac{v_{\text{obs}}^2(R_\odot)}{v_b^2(R_\odot)} \approx \frac{230^2}{150^2} \approx 2.35. \quad (19)$$

This is exactly the kind of amplification that, in Newtonian language, is attributed to the NFW halo fit by Totani.

4.2. Constraint on (ε, k_0) from the Milky Way

In FMP, $D(R)$ is given by Eq. (10),

$$D(R) = 1 + \varepsilon F(1/R) = 1 + \varepsilon \frac{1}{1 + (R/L_0)^2}, \quad (20)$$

where we have written $L_0 \equiv k_0^{-1}$. At $R_\odot$, Eq. (19) yields

$$2.35 \approx 1 + \varepsilon \frac{1}{1 + (R_\odot/L_0)^2}. \quad (21)$$

Solving for ε in terms of L_0 gives

$$\varepsilon(L_0) \approx 1.35 [1 + (R_\odot/L_0)^2]. \quad (22)$$

For L_0 in the range indicated by galaxy and cluster fits, cf. Eq. (13), we obtain:

- $L_0 = 10 \text{ kpc}$: $(R_\odot/L_0)^2 \simeq (8/10)^2 \simeq 0.64$, so $F \simeq 1/1.64 \simeq 0.61$ and $\varepsilon \simeq 1.35/0.61 \simeq 2.2$;
- $L_0 = 15 \text{ kpc}$: $(R_\odot/L_0)^2 \simeq (8/15)^2 \simeq 0.28$, so $F \simeq 1/1.28 \simeq 0.78$ and $\varepsilon \simeq 1.35/0.78 \simeq 1.7$;
- $L_0 = 20 \text{ kpc}$: $(R_\odot/L_0)^2 \simeq (8/20)^2 \simeq 0.16$, so $F \simeq 1/1.16 \simeq 0.86$ and $\varepsilon \simeq 1.35/0.86 \simeq 1.6$.

Thus the Milky Way amplification implied by the *Fermi* halo is consistent with

$$\varepsilon \approx 1.6\text{--}2.2, \quad L_0 \approx 10\text{--}20 \text{ kpc}, \quad (23)$$

in excellent agreement with the range deduced from independent FMP fits to external galaxies and clusters [21,22].

The mild core suggested by the *Fermi* halo profile—better modelled by an Einasto profile than by a strict NFW cusp—also fits well with the real-space behaviour of the Lorentzian kernel. The

Yukawa-like fall-off on scales $r \lesssim L_0$ naturally smooths the innermost potential relative to a pure $1/r$ cusp, while still approximating an NFW-like profile at intermediate radii.

In summary, once the NFW halo inferred from gamma rays is identified with the FMP future-mass distribution ρ_F of the Milky Way, the resulting (ε, k_0) are neither extreme nor tuned: they fall squarely in the region already required by FMP to explain other gravitational phenomena.

5. Gamma-Ray Emission in the FMP Potential

In the WIMP interpretation of the *Fermi* halo, the gamma-ray emissivity is taken to be proportional to ρ_{DM}^2 ,

$$Q_\gamma(E, \mathbf{r}) \propto \langle \sigma v \rangle \rho_{\text{DM}}^2(\mathbf{r}) \frac{dN_\gamma}{dE}, \quad (24)$$

where dN_γ/dE is the spectrum per annihilation. The effective density ρ_{DM} is simply the NFW fit, and the cross section is given by Eq. (15). As discussed in Sec. 3, this leads to tensions with dwarf-galaxy and extragalactic gamma-ray limits.

In FMP, the halo profile fitted by Totani is not a separate particle component, but the future-mass density ρ_F that appears in the gravitational Poisson equation. The gamma-ray emissivity remains of baryonic origin, dominated by cosmic-ray (CR) interactions:

$$Q_\gamma(E, \mathbf{r}) \simeq Q_{\pi^0}(E, \mathbf{r}) + Q_{\text{ICS}}(E, \mathbf{r}) + \dots, \quad (25)$$

with

$$Q_{\pi^0}(E, \mathbf{r}) \propto n_{\text{CR,p}}(\mathbf{r}) n_{\text{gas}}(\mathbf{r}) \sigma_{pp \rightarrow \pi^0 \rightarrow \gamma\gamma}(E), \quad (26)$$

and

$$Q_{\text{ICS}}(E, \mathbf{r}) \propto n_{\text{CR,e}}(\mathbf{r}) u_{\text{rad}}(\mathbf{r}) \sigma_{\text{ICS}}(E). \quad (27)$$

Here $n_{\text{CR,p}}$ and $n_{\text{CR,e}}$ are the proton and electron cosmic-ray densities, n_{gas} is the gas density, and u_{rad} is the target photon energy density.

The key difference under FMP is not the microphysics of CR interactions, but the large-scale gravitational potential in which CRs diffuse and advect. The steady-state CR transport equation in the halo can be written schematically as

$$\nabla \cdot [D(E, \mathbf{r}) \nabla n_{\text{CR}} - \mathbf{v}_{\text{adv}} n_{\text{CR}}] - \frac{\partial}{\partial E} [b(E, \mathbf{r}) n_{\text{CR}}] + \frac{n_{\text{CR}}}{\tau_{\text{loss}}(E, \mathbf{r})} = Q_{\text{inj}}(E, \mathbf{r}), \quad (28)$$

where D is the diffusion coefficient, $\mathbf{v}_{\text{adv}}$ is an advective or convective velocity, $b(E)$ encodes continuous energy losses, τ_{loss} accounts for catastrophic losses, and Q_{inj} is the source term.

The FMP future-mass potential Φ_F contributes to the total gravitational potential $\Phi_{\text{eff}} = \Phi_b + \Phi_F$, thereby affecting both the CR confinement volume and any large-scale outflows. A deeper, more extended potential halo increases the residence time of CRs at large radii, enhances the high-latitude gas density relative to a purely baryonic potential, and changes the balance between diffusion and advection. These modifications can produce an extended, approximately spherical halo of gamma-ray emission that is qualitatively similar to the one inferred in Ref. [25], without requiring ρ_{DM}^2 annihilation.

In a simple toy model, one can assume that:

- CR sources follow the star-forming disk,
- CRs propagate into the halo under diffusion and a slow FMP-induced inflow velocity $\mathbf{v}_F \sim -\nabla \Phi_F$,
- the gas density falls off with radius but is partially supported by the deeper FMP potential,
- the result is a smooth CR halo with density $n_{\text{CR}}(r)$ that traces the effective potential.

Under these assumptions, the line-of-sight integral for the gamma-ray intensity,

$$I_\gamma(E, \hat{\Omega}) \propto \int ds Q_\gamma(E, \mathbf{r}), \quad (29)$$

naturally produces a large-scale halo component whose angular profile can approximate an NFW-like shape in projection, especially if $n_{\text{CR}}(r)$ depends exponentially on $-\Phi_{\text{eff}}(r)$.

A detailed CR transport calculation in an FMP potential is beyond the scope of this work and is left for future study. The central point here is that once the gravitational potential is fixed by (ε, k_0) , the same CR physics used in standard GALPROP-based modelling can generate an extended gamma-ray halo, making baryonic explanations more plausible than in a purely baryon-only potential.

Finally, suppose that WIMPs do exist on top of FMP, contributing a subdominant true dark-matter density $\rho_{\text{DM}}^{(\text{true})}$. The *Fermi* halo analysis would then have double-counted the FMP future mass as if it were $\rho_{\text{DM}}^{(\text{true})}$. To avoid overshooting the observed rotation curve and lensing, the true particle component must be at most a modest fraction of the effective NFW halo. A conservative estimate is that only $\lesssim 30\%$ of the dynamical halo can be attributed to particles; the rest is already encoded in ρ_F . This would rescale Eq. (15) to

$$\langle\sigma v\rangle_{\text{max}} \sim 0.3 \times (5-8) \times 10^{-25} \text{ cm}^3 \text{ s}^{-1} \simeq (1.5-2.4) \times 10^{-25} \text{ cm}^3 \text{ s}^{-1}, \quad (30)$$

which is closer to, but still somewhat above, existing limits. In other words, in an FMP Universe the *Fermi* halo does not provide evidence for WIMPs, but rather an upper limit on any such component in addition to the future mass.

6. Discussion and Conclusions

The *Fermi*-LAT detection of a smooth, approximately spherical gamma-ray halo around the Milky Way, with a spectrum peaking near $E_\gamma \sim 20$ GeV and morphology well fitted by an NFW profile, has naturally attracted attention as a potential indirect signal of dark-matter annihilation [25]. If interpreted in the standard WIMP framework, the preferred cross section lies significantly above both the canonical thermal relic value and existing limits from dwarf spheroidal galaxies and the extragalactic gamma-ray background. Although uncertainties in the Milky Way halo profile and substructure may soften this tension, the particle-dark-matter interpretation remains stressed.

In the Future-Mass Projection framework, the same halo profile is not mysterious. FMP predicts an extended future-mass density ρ_F around baryonic mass distributions, produced by a bilocal kernel that correlates points along a closed time path. In the Newtonian limit this modifies the Poisson equation and yields an effective amplification of the Newtonian potential controlled by a Lorentzian form factor with parameters (ε, k_0) . Fits to external galaxies and clusters already indicate $\varepsilon \sim \mathcal{O}(1-3)$ and $L_0 \sim \mathcal{O}(5-20 \text{ kpc})$.

By identifying the NFW halo inferred from *Fermi* gamma-ray data with the Milky Way's future-mass distribution ρ_F , we have shown that the required amplification of the rotation curve at the solar radius implies $\varepsilon \simeq 1.6-2.2$ for $L_0 \simeq 10-20 \text{ kpc}$. These values lie squarely within the range already favoured by SPARC rotation curves and Bullet-Cluster lensing, and are compatible with the cosmological ratio $R_0 = \Omega_F/\Omega_b \simeq 5.4$. The mild core in the halo profile, better fitted by an Einasto law than by a pure NFW cusp, is a natural consequence of the finite FMP horizon.

In this reinterpretation, the 20 GeV gamma-ray excess originates from baryonic cosmic-ray emission in the FMP-modified potential, not from ρ_{DM}^2 annihilation. The effective halo detected by *Fermi* becomes a calibration point for the nonlocal kernel, rather than a first glimpse of a new particle. If WIMPs exist at all, their contribution to the Milky Way potential must be subdominant to ρ_F , and the *Fermi* halo provides an upper bound rather than a detection.

Future work should include:

- a full CR transport calculation in the FMP potential of the Milky Way, using GALPROP-like tools with an FMP gravity module,
- a joint fit of *Fermi* halo data, rotation curves, and lensing constraints for the Milky Way in the FMP framework,

- applications of the same methodology to other galaxies with gamma-ray halo measurements, if available,
- a systematic assessment of how FMP modifies global extragalactic gamma-ray backgrounds relative to standard Λ CDM.

From the point of view of FMP gravity, the new *Fermi* halo is therefore not a challenge but an additional, nontrivial test that the same bilocal kernel can pass simultaneously on galactic, cluster, cosmological, and now gamma-ray scales.

Funding: No external funding was received for this work.

Data Availability Statement: This study uses published *Fermi*–LAT data and results. All data and analysis products referenced are available in Ref. [25] and in the public *Fermi*–LAT archives.

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

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