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Dark Matter as a Geometric Necessity of Four-Dimensional Spacetime:

A Dimensional Degeneracy Hypothesis

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Abstract

We propose that dark matter is not an exotic new substance, but a **geometric necessity** of four-dimensional spacetime. Prior to the electroweak Higgs phase transition, all fundamental particles were massless and propagated at the speed of light c. In this pre-Higgs epoch, the four dimensions of spacetime were fully equivalent – no dimension was geometrically privileged as "time". Upon Higgs condensation, the acquisition of mass froze each particle's instantaneous propagation axis as its individual time dimension, while the remaining three orthogonal dimensions became its spatial dimensions. Since exactly four basis dimensions are available, this produces **four distinct dimensional sectors**: one visible sector (our own) and three geometrically equivalent dark sectors. Particles across sectors share the same four-dimensional manifold and thus interact gravitationally. Electromagnetic interactions – being confined to a shared three-dimensional spatial hypersurface – are geometrically forbidden between sectors. Dark matter thus requires no new particles, no new forces, and no modifications to gravity: it is a direct consequence of the combinatorial geometry of (3+1)-dimensional spacetime. The predicted dark-to-visible matter ratio of 3 : 1 is consistent with cosmological observations. The structural co-distribution of dark and visible matter emerges naturally from their shared gravitational manifold. Furthermore, the hypothesis provides a geometric explanation for the Hubble tension, predicts gravitational wave events without electromagnetic counterparts, and accounts for the persistent null results of all direct dark matter detection experiments.

Keywords: dark matter; spacetime geometry; dimensional degeneracy; Higgs phase transition; geometric origin; structure formation; electroweak symmetry breaking; Hubble tension; gravitational waves

Contents

1. Introduction: A Geometric Perspective on Dark Matter

The nature of dark matter is one of the deepest unsolved problems in physics. Observational evidence is overwhelming: galactic rotation curves [1], the dynamics of galaxy clusters [2], the angular power spectrum of the Cosmic Microwave Background [3], and the large-scale structure of the Universe [4] all point to a dominant non-luminous matter component comprising approximately 80% of all matter.

Yet despite decades of experimental effort, no dark matter particle has been directly detected. WIMPs [5], axions [6, 7], sterile neutrinos [8], and primordial black holes [9] remain unconfirmed. Modified gravity theories [10, 11] face difficulties at cluster scales [2]. The field is characterized by an abundance of candidates and an absence of conclusive evidence.

We suggest that this impasse may reflect a deeper issue: the search for dark matter has been almost exclusively directed toward new *particles* or new *forces*, while the possibility of a purely *geometric* origin – rooted in the structure of spacetime itself – has received comparatively little attention outside extra-dimensional frameworks.

> **Central Thesis.** Dark matter is not a new form of substance. It is a geometric consequence of the four-dimensional structure of spacetime, made manifest at the moment of the Higgs electroweak phase transition. The same spacetime that produces one visible sector necessarily produces three geometrically equivalent dark sectors. Their invisibility is not a material property – it is a geometric one.

Philosophical Implications

This framework implies a fundamentally different picture of physical reality. If four-dimensional spacetime necessarily produces four geometrically equivalent sectors, then what we call "the Universe" is only one quarter of the total material content of the same spacetime manifold. The three dark sectors are not located *elsewhere* – they are not bubble universes in an inflating multiverse, nor branes separated by extra-dimensional bulk. They exist *here*, *now*, and *everywhere*, permeating the same spatial volume we inhabit, invisible not because of distance or shielding, but because of a geometric incompatibility established at the earliest moments of the Universe.

> *"The Universe we observe is not the Universe that exists. It is one of four geometrically equivalent projections of a single four-dimensional reality – distinguished from the others not by position, not by substance, but solely by the orientation of its time axis."*

This stands in sharp contrast to conventional multiverse proposals. In inflationary bubble multiverse scenarios [26], parallel universes are causally disconnected regions of spacetime. In the framework proposed here, the "other universes" are gravitationally coupled to our own at every point in space – they are co-present, co-extensive, and co-gravitating. Their existence is not a speculative extrapolation: it is, we argue, a direct consequence of the geometry we already know.

We cannot, even in principle, directly observe the other sectors. This is not a technological limitation – it is a geometric fact. Electromagnetic observation requires a shared three-dimensional spatial hypersurface, which the sectors do not share by construction. Gravity – the only sector-blind force – is therefore not merely a tool for detecting dark matter, but the *only possible bridge* between the sectors.

This paper is structured as follows. Section 2 establishes the geometric foundation. Section 3 presents dimensional freezing and the four sectors. Section 4 demonstrates observational consistency and develops specific predictions. Section 5 identifies open challenges.

2. The Geometry of Pre-Higgs Spacetime

2.1 The Minkowski Metric and the Asymmetry of Time

The spacetime of special relativity [14] carries the invariant interval

$$ds^2 = -c^2\,dt^2 + dx^2 + dy^2 + dz^2. \tag{1}$$

The negative sign encodes the fundamental geometric asymmetry between time and space. Under the Wick rotation $t \mapsto \tau = i\,t$ this becomes a fully Euclidean metric,

$$ds_E^2 = d\tau^2 + dx^2 + dy^2 + dz^2, \tag{2}$$

in which all four dimensions are geometrically equivalent and the distinction between "time" and "space" dissolves entirely.

2.2 Dimensional Democracy Before Mass Generation

A massless particle propagating at c experiences no preferred time direction: its proper time does not advance, and its spatial extent along the propagation axis vanishes by Lorentz contraction (Eq. (4)). For a photon, the distinction between "time" and "space" is already geometrically degenerate.

Postulate 1 (Dimensional Democracy)**.** *Prior to the Higgs phase transition, when all particles were massless and propagated at c, no dimension of the four-dimensional spacetime manifold was geometrically privileged as the temporal dimension. The four basis vectors $\{e_0, e_1, e_2, e_3\}$ were fully equivalent; any dimension was equally capable of assuming the role of time for a given particle, determined solely by that particle's propagation direction.*

Postulate 1 extends Einstein's principle of relativity – no inertial frame is preferred – to the dimensional structure of the manifold itself.

2.3 The Higgs Transition as the Origin of Geometric Asymmetry

The electroweak phase transition at $T_c \approx 160\,\text{GeV}$ ($\approx 10^{-12}\,\text{s}$ after the Big Bang) introduces mass into the Universe [12, 13]. Below T_c the Higgs field acquires a non-zero vacuum expectation value $\langle\phi\rangle = v \approx 246\,\text{GeV}$, and fermion masses arise via Yukawa couplings:

$$m_f = y_f \cdot \frac{v}{\sqrt{2}}. \tag{3}$$

We propose that this is simultaneously the moment at which the **geometric asymmetry between time and space is established for each individual particle**. The Higgs transition is a symmetry breaking in the Higgs field *and* in the dimensional structure of spacetime.

3. Dimensional Freezing and the Four Sectors

3.1 The Mechanism: Freezing a Direction as Time

At the moment of mass acquisition each formerly massless particle was propagating at c along some direction in the four-dimensional manifold. Two relativistic results apply simultaneously:

Lorentz contraction.

$$L = L_0\sqrt{1 - \frac{v^2}{c^2}} \longrightarrow 0 \qquad \text{as} \quad v \to c. \tag{4}$$

The spatial extent along the propagation axis vanishes at c: that axis behaves as a temporal, not a spatial, dimension.

Time dilation. A particle at c has zero proper-time advancement; its propagation axis is "pure time" for any observer.

Upon mass acquisition the particle slows below c. The previously degenerate propagation axis is **frozen as the particle's time dimension**; the three orthogonal directions become its spatial dimensions. We call this event **dimensional freezing**.

Formally, the **dimensional assignment** of particle p is the map

$$D_p : \{e_0, e_1, e_2, e_3\} \longrightarrow \{\text{time},\ x,\ y,\ z\}, \tag{5}$$

where the frozen propagation axis maps to "time" and the remaining three basis vectors map to spatial dimensions.

3.2 The Four Geometric Sectors

Equation (5) admits exactly **four** distinct assignments in a four-dimensional spacetime:

$$\begin{aligned} D_0 &: \ \text{time} = e_0, \quad \text{space} = \{e_1, e_2, e_3\} \quad [\text{visible sector}] \\ D_1 &: \ \text{time} = e_1, \quad \text{space} = \{e_0, e_2, e_3\} \quad [\text{dark sector 1}] \\ D_2 &: \ \text{time} = e_2, \quad \text{space} = \{e_0, e_1, e_3\} \quad [\text{dark sector 2}] \\ D_3 &: \ \text{time} = e_3, \quad \text{space} = \{e_0, e_1, e_2\} \quad [\text{dark sector 3}]. \end{aligned} \tag{6}$$

Proposition 1 (Dark Matter as Geometric Multiplicity)**.** *Four-dimensional spacetime admits exactly four geometrically equivalent dimensional sectors. Under isotropic distribution of propagation directions at T_c, each sector is equally populated. Three of the four sectors are dark with respect to any single observer sector. The predicted dark-to-visible matter ratio is $3:1$, consistent with the cosmologically observed value of approximately 80% dark matter.*

The $3:1$ ratio is not a free parameter. It is a **topological consequence of the dimension of spacetime**: in n dimensions there would be n sectors and a dark-to-visible ratio of $(n-1):1$.

3.3 Geometric Origin of Coupling Selectivity

Gravity couples across all sectors. Einstein's field equations,

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}, \tag{7}$$

are defined on the full four-dimensional manifold; the indices $\mu, \nu \in \{0, 1, 2, 3\}$ span all four basis dimensions regardless of how particles partition them. Every particle, in every sector, responds to the same geometry. **Gravity is sector-blind because it is fundamentally four-dimensional.**

Electromagnetism is confined to spatial hypersurfaces. Two particles can exchange photons only if they share the same three-dimensional spatial subspace. Particles in different sectors share at most two spatial basis dimensions and therefore do not inhabit a common three-dimensional hypersurface. **Electromagnetic coupling between sectors is geometrically forbidden.**

Dark matter is dark not because it lacks charge, but because it inhabits a geometrically distinct spatial subspace.

4. Observational Consistency and Predictions

4.1 Matter Abundance: The $3:1$ Ratio

Proposition 1 implies that exactly 3/4 of all matter is dark – in agreement with cosmological measurements placing dark matter at $\approx 27\%$ of total energy density, or $\sim 80\%$ of total matter [3], with no free parameters.

4.2 Structural Co-distribution

Recent ultra-high-resolution weak lensing maps from the James Webb Space Telescope [20] reveal rich dark matter substructure closely mirroring the distribution of visible matter. In the geometric framework this co-distribution is *expected*: all four sectors originate from the same primordial quantum fluctuations and evolve in the same gravitational potential (7). The cosmic web is a structure of the four-dimensional manifold and is therefore **identical across all sectors by construction**.

4.3 Early Structure Formation and JWST Anomaly

Sectors D_1, D_2, D_3 decouple from the photon-baryon plasma immediately after the Higgs transition and begin gravitational collapse unimpeded by radiation pressure. The presence of three dark sectors – each independently seeding gravitational potentials – may explain the overabundance of massive galaxies at very high redshift reported by JWST [19]: the effective gravitational seed density is three times larger than single-sector models assume.

4.4 Bullet Cluster: Low Dark Matter Self-Interaction

Particles in dark sectors D_1, D_2, D_3 share no common three-dimensional spatial hypersurface even among themselves, implying negligible electromagnetic self-interaction across dark sectors [2]. The only inter-sector coupling is gravitational, too weak to produce observable ram pressure on cluster-collision timescales.

4.5 The Hubble Tension as a Multi-Sector Effect

The $\sim 5\sigma$ discrepancy between CMB-inferred [3] $H_0 \approx 67.4 \pm 0.5\,\mathrm{km\,s^{-1}Mpc^{-1}}$ and the local distance-ladder value [21] $H_0 \approx 73.0 \pm 1.0\,\mathrm{km\,s^{-1}Mpc^{-1}}$ has resisted resolution within ΛCDM.

In our framework the total gravitational content of the Universe is the coherent superposition of all four sector densities. CMB-based measurements probe the *global* early-Universe content – the sum of all four sectors before significant structure formation. Local distance-ladder measurements probe the *late-time* structured Universe, where the three dark sectors may have developed slightly different clustering properties due to their electromagnetic inertness and distinct initial perturbation phases. The locally measured expansion rate would then systematically differ from the globally inferred value.

Remark 1. *The Hubble tension, in the geometric framework, is a signature of the multi-sector gravitational landscape: early-Universe measurements average over all four sectors globally, while late-Universe measurements are sensitive to a local structure in which dark sectors may not perfectly trace visible matter. A quantitative prediction of ΔH_0 requires a full four-sector perturbation theory, identified here as a priority for future work.*

4.6 Gravitational Wave Events Without Electromagnetic Counterparts

The LIGO/Virgo/KAGRA collaboration [22] has established multi-messenger astronomy. Binary neutron star event GW170817 produced coincident gravitational waves and a gamma-ray burst [23]. However, several gravitational wave events – particularly binary black hole mergers – have been detected *without any electromagnetic counterpart*, even under favorable observational conditions.

The Dimensional Degeneracy Hypothesis suggests a novel interpretation: some silent events may represent **mergers between compact objects belonging to different dimensional sectors**. A merger between a compact object in sector D_0 and one in sector D_i ($i \neq 0$) would:

- generate a gravitational wave signal detectable by LIGO/Virgo/KAGRA, since gravitational radiation perturbs the full four-dimensional metric;
- produce *no electromagnetic counterpart at any wavelength*, not because the objects are electromagnetically quiet but because the dark-sector object has no coupling to our spatial hypersurface;
- potentially exhibit anomalous mass ratios or asymmetric waveform features reflecting different formation histories.

Proposition 2 (Cross-Sector Merger Signature)**.** *Gravitational wave events involving one visible-sector object and one dark-sector object produce no associated electromagnetic emission at any wavelength. A statistical excess of electromagnetically silent gravitational wave events above the rate expected from standard binary black hole populations constitutes a* ***falsifiable prediction*** *of cross-sector mergers, testable with Einstein Telescope and LISA data.*

4.7 Null Results in Direct Detection Experiments

Experiments LUX, XENON, PandaX, CDMS, DarkSide, LUX-ZEPLIN, and XENONnT search for nuclear recoil from dark matter scattering. Despite reaching sensitivities many orders of magnitude below their design targets, all have returned null results [24, 25]. Within the WIMP paradigm this merely shrinks the allowed cross-section parameter space.

The geometric framework provides a principled explanation for why *every* such experiment will necessarily fail:

Geometric Prediction: Direct Detection is Impossible.
Dark matter particles inhabit a sector sharing no common three-dimensional spatial hypersurface with visible matter. Any non-gravitational interaction – nuclear scattering, electronic recoil, any Standard Model channel – requires a shared local spatial subspace that dark matter, by geometric construction, does not possess. No direct detection experiment based on non-gravitational interactions can ever detect dark matter of this type: not as a consequence of weak coupling, but of geometric inaccessibility.

The null results of LUX-ZEPLIN, XENONnT, and their predecessors are therefore not failures requiring explanation – they are **positive confirmations** of the geometric prediction.

Remark 2. *The hypothesis is falsifiable in both directions: a confirmed excess of electromagnetically silent gravitational wave events supports it; a confirmed non-gravitational direct detection signal refutes it.*

4.8 Summary of Observational Predictions

5. Open Challenges

This paper presents a conceptual hypothesis, not a complete theory. The following challenges must be resolved for it to become formally viable.

5.1 Formalizing Dimensional Assignment

The map D_p in Eq. (5) is currently defined conceptually. A rigorous formulation requires a mathematical framework in which distinct dimensional assignments coexist within a single four-dimensional manifold. The tetrad (vierbein) formalism of General Relativity – in which local frame orientations are defined independently at each spacetime point – offers a natural starting point. The challenge is to generalize this to allow particle-dependent frame orientations that become fixed at the phase transition rather than remaining gauge-free.

5.2 Symmetry Group and Lorentz Structure

The Lorentz group $SO(1,3)$ treats temporal and spatial dimensions asymmetrically. If different particles carry different dimensional assignments, they transform under different representations. A consistent multi-sector theory must identify the overarching symmetry group for all four sectors – a natural candidate being $SO(4)$, the Euclidean rotation group treating all four basis directions equivalently. The Higgs transition would then correspond

Table 1: Observational predictions of the Dimensional Degeneracy Hypothesis and their current status.

Observable	**Geometric explanation**	**Status**
DM electromagnetically inert	No shared 3D spatial hypersurface across sectors	**Consistent**
DM gravitationally coupled	Gravity defined on full 4D manifold	**Consistent**
DM/visible ratio $\approx 3:1$	Exactly 4 sectors in 4D spacetime	**Consistent**
Structural co-distribution (JWST)	Shared gravitational manifold	**Consistent**
Bullet Cluster (no self-interaction)	No inter-sector EM coupling	**Consistent**
Null results in direct detection	Geometric inaccessibility of dark sectors	**Predicted**
Hubble tension (ΔH_0)	Differential sector clustering	**Qualitative**
Silent GW events (LIGO/LISA)	Cross-sector compact object mergers	**Testable**
JWST massive early galaxies	$3\times$ gravitational seed density	**Suggestive**
CMB power spectrum (quantitative)	Requires four-sector perturbation theory	**Open**

to spontaneous breaking $SO(4) \to SO(1,3)$, selecting a time direction for each particle independently.

5.3 The Freezing Mechanism

A rigorous derivation must show how a Lorentz-scalar condensate $\langle\phi\rangle$ – which carries no intrinsic directional information – can nevertheless select a dimensional orientation for each particle. One avenue treats the propagation direction as a quasi-classical variable that decoheres at the phase transition, analogous to the classicalization of quantum fluctuations during inflation.

5.4 Quantitative Predictions

The framework must yield computable predictions for:

- the matter power spectrum of the dark sectors;
- CMB temperature and polarization anisotropies under the four-sector model;
- the quantitative contribution of multi-sector gravitational superposition to ΔH_0;
- the expected rate and waveform characteristics of cross-sector compact object mergers for LISA and Einstein Telescope.

5.5 Consistency with Quantum Field Theory

The framework must be compatible with the renormalization group structure of the Standard Model and must introduce no anomalies or unitarity violations. The Clifford algebra structure underlying the Dirac equation depends on the metric signature and must be generalized to accommodate multiple simultaneous signatures.

5.6 Relation to Extra-Dimensional Frameworks

The proposal shares structural features with braneworld models [17] and Kaluza-Klein theories [15, 16]. The key distinction is that the four sectors are not spatially separated branes but geometrically orthogonal orientations of the *same* four-dimensional manifold. A careful comparative analysis – identifying predictions unique to this proposal – is an important direction for future work.

6. Conclusion

We have proposed that dark matter is a **geometric necessity** of four-dimensional spacetime. The argument is the following:

1. Before the Higgs phase transition, all four spacetime dimensions were geometrically equivalent (dimensional democracy, Postulate 1).

2. At the Higgs transition, each particle's propagation axis was frozen as its time dimension, producing four geometrically distinct sectors (Eq. (6)).

3. Gravity, defined on the full four-dimensional manifold, couples all sectors universally. Electromagnetism, confined to three-dimensional spatial hypersurfaces, couples only within sectors.

4. The three dark sectors are electromagnetically invisible but gravitationally present – precisely the defining properties of dark matter.

5. The dark-to-visible ratio of 3 : 1 follows from pure combinatorics in four dimensions, with no free parameters (Proposition 1).

6. The Hubble tension finds a natural qualitative explanation in the differential evolution of multi-sector gravitational densities between the early and late Universe.

7. Electromagnetically silent gravitational wave events are a direct, falsifiable prediction of cross-sector compact object mergers (Proposition 2).

8. The persistent null results of all direct dark matter detection experiments are geometric predictions confirmed – not failures requiring explanation.

This framework requires no new particles, no new forces, and no modifications to General Relativity. Dark matter is not an anomaly demanding exotic new physics: it is an expression of the geometry of the spacetime we already inhabit. The three dark sectors are not elsewhere. They are here – co-present, co-extensive, and co-gravitating with our own Universe, separated from us not by space, not by time, but solely by the orientation of a single dimension frozen at the dawn of mass itself.

The central open challenge is mathematical formalization: a covariant field-theoretic description of sector-dependent dimensional assignments, a derivation of the freezing mechanism from first principles, and a four-sector perturbation theory capable of yielding quantitative predictions for the CMB, large-scale structure, and the Hubble tension. We offer this geometric perspective as an invitation to the community to assess whether the four-dimensional structure of spacetime is itself the origin of the Universe's dominant matter component.

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