A Geometric Shell Framework for Fields, Gravity, and the Dark Sector (The Shell Model)

Modern cosmology rests on an uneasy balance. General relativity describes gravity with extraordinary precision, while quantum field theory successfully accounts for the particles and forces of the Standard Model. Yet the Universe we observe appears to be dominated by dark components, dark matter and dark energy, that fit neither framework naturally. These dark sectors are typically introduced as new substances or parameters, added to otherwise well-tested equations.

An alternative possibility is that the dark sector is not a new form of matter or energy at all, but a manifestation of geometry. In this article, I outline a geometric shell framework in which gravity, fields, and the dark sector emerge from a hierarchy of internal geometric structures, without modifying Einstein's equations or introducing exotic particles.

The framework is exploratory and proposes a geometric reinterpretation of known physical sectors rather than a finished fundamental theory.

Gravity as geometry — but only in spacetime

Einstein's great insight was that gravity is not a force but the curvature of spacetime. However, this statement is often taken too far. In many modern theories, curvature, dimensions, or metrics are assigned to abstract internal spaces and then treated as gravitational in character. This can blur an important distinction.

In the shell framework, gravity exists only when spacetime is Lorentzian — that is, when a four-dimensional manifold possesses a metric with causal structure and a Levi–Civita connection. Only then does the Einstein–Hilbert action define a dynamical theory and only then do Einstein's equations apply.

Before this point, geometry exists, but gravity does not.

This distinction is central. Internal geometric structures may organise symmetry, curvature, and topology, but they do not generate gravity directly. Instead, they contribute effective energy–momentum once spacetime exists, sourcing curvature without altering the gravitational law itself.

From shells, not dimensions

The shell framework does not posit extra spacetime dimensions beyond the familiar four. Instead, it introduces a hierarchy of internal geometric shells, each characterised by a specific symmetry or holonomy. These shells are organisational layers, not physical locations.

Some shells are continuous and geometric; others are discrete and algebraic. At the highest level lies a pregeometric scaffold defined by modular and orthogonal symmetry groups. Below this, progressively more structured geometric shells appear, culminating in four-dimensional spacetime.

Crucially, no internal manifold exceeds eight real dimensions, avoiding a common conceptual pitfall of higher-dimensional theories. The number of shells reflects symmetry capacity, not spatial extension.

Quantum behaviour from hidden geometry

The separation between four-dimensional spacetime and higher internal shells also suggests a geometric perspective on quantum behaviour. In this view, some phenomena usually described purely by wavefunctions may instead reflect information encoded in deeper geometric structure and only partially realised in spacetime observables.

Quantum tunnelling may be interpreted as arising when geometric pathways in internal shells bypass barriers that exist only in spacetime, and quantum non-locality may reflect shared higher-shell structure rather than superluminal signalling. From this perspective, quantum mechanics is not a breakdown of causality, but an effective description of deeper geometric organisation that becomes visible only when projected into four dimensions.

Fields versus energy: two geometric channels

A key insight of the framework is the separation of three geometric channels: fields from surface geometry, effective energy densities from averaged volume geometry, and gravitational coupling from integrated internal geometry.

Certain internal geometries naturally support gauge fields and matter. In particular, six-dimensional Calabi–Yau manifolds organise the vacuum structure of the Standard Model, giving rise to gauge symmetries and particle families through dimensional reduction. However, this higher-dimensional structure is not realised directly in four dimensions. Instead, it passes through an intermediate geometric layer associated with five-dimensional Sasaki–Einstein manifolds. This layer acts as a projection interface, converting higher-dimensional symmetry into effective four-dimensional gauge structure while constraining which fermionic modes remain physically admissible. These are field-generating shells, but their physical realisation is governed by this intermediate geometry.

This distinction also clarifies a fundamental difference between bosons and fermions. Gauge bosons arise from geometric connections and curvature and therefore descend robustly under projection. Fermions, by contrast, arise from spinor structures and depend on the spectral properties of the underlying geometry. As a result, only a restricted set of fermionic modes survives the projection through the Sasaki–Einstein layer. In this way, the observed matter content reflects not only what is geometrically possible, but also what is geometrically admissible.

Other geometries do something very different. They do not produce fields at all, but instead store geometric energy.

Spin(7) manifolds support torsion without gauge fields. This torsional structure is non-radiative, pressureless, and saturating. When projected into spacetime, it behaves like cold dark matter.

G_2 manifolds, by contrast, carry Ricci curvature that relaxes slowly under geometric flow. This residual curvature appears in spacetime as an effective vacuum energy with negative pressure, corresponding to dark energy.

A useful way to distinguish these channels is geometrically. Field-generating shells act like surfaces: their structure organises gauge connections and particle content without storing bulk energy. Energy-generating shells act like volumes: they store curvature or torsion that projects into spacetime as energy density but does not give rise to fields. This surface–volume distinction explains why Standard Model fields and the dark sector arise from different internal geometries, despite sharing a common spacetime projection.

Why gravity is unchanged

One of the most important features of the shell framework is what it does not do.
It does not:

- modify Einstein's equations,
- introduce scalar–tensor gravity,
- add fifth forces,
- or alter spacetime dynamics.

All contributions from internal shells enter only on the right-hand side of Einstein's equations, as effective energy–momentum. The left-hand side — the geometric law of gravity — remains untouched. This sharply distinguishes the framework from modified-gravity models and places it firmly within standard general relativity.

The effective four-dimensional gravitational coupling is fixed once spacetime emerges, determined by an integral over internal geometry, and remains constant throughout a cycle even as curvature channels exhaust.

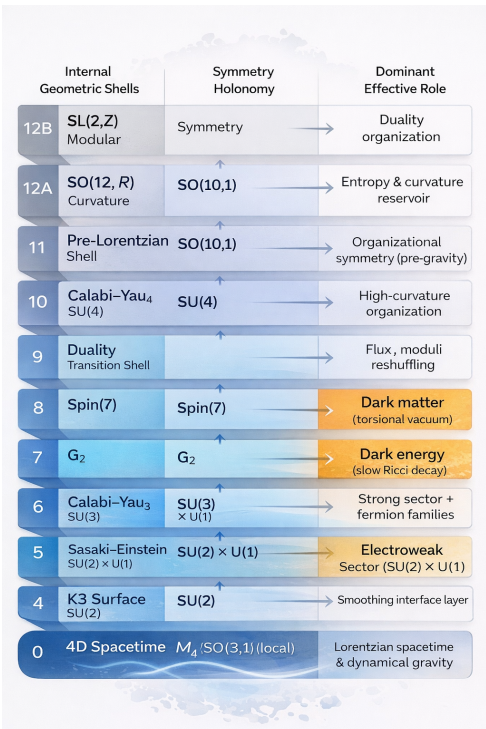

Fig. 1 The Geometric Shell Model of physical emergence.

A schematic illustration of the Shell Model showing the hierarchical organisation of geometry from a discrete, modular pre-geometric limit at the top (SL(2,ℤ)) through successive internal geometric shells, down to four-dimensional Lorentzian spacetime at the base. Each shell represents a distinct layer of symmetry, holonomy, and curvature organisation rather than an additional spacetime dimension. Gravity emerges only at the lowest shell, where a Lorentzian metric and Einstein dynamics become defined, while higher shells contribute effective energy–momentum content interpreted as dark energy, dark matter, and gauge structure.

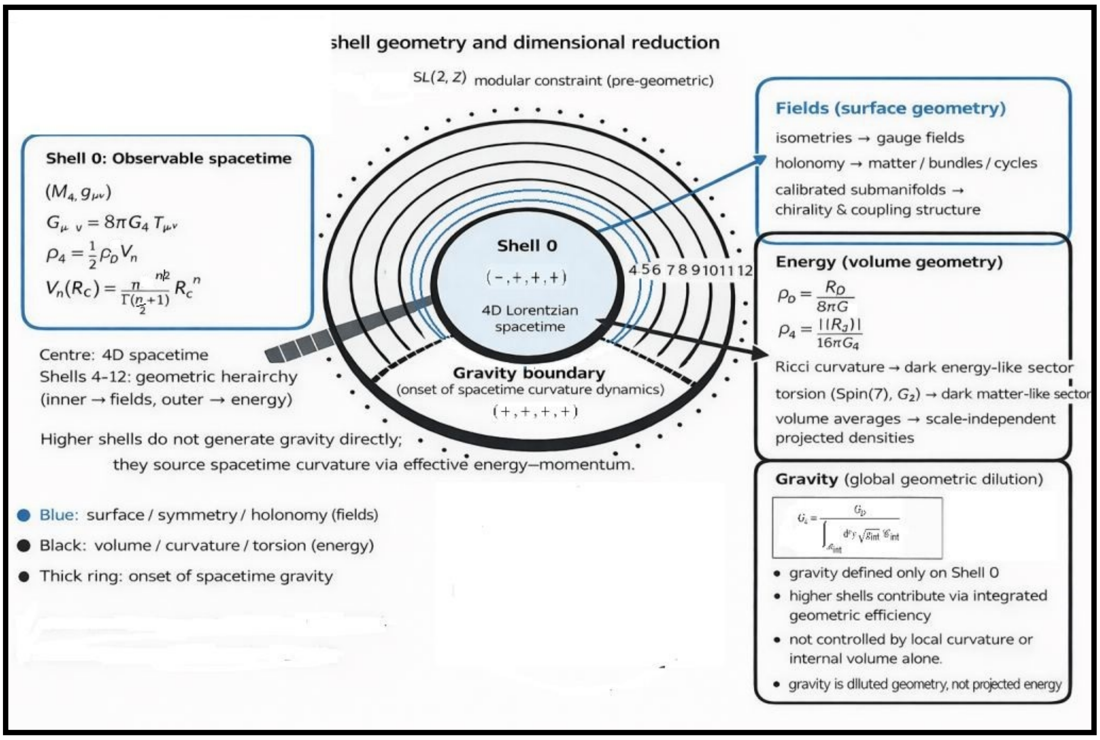

Fig. 2. Figure 2: Schematic of dimensional reduction

Mathematical Anchors of the Shell Framework

Although the shell framework is geometric in spirit, several compact equations capture its central claims.

Effective gravitational coupling

The observed four-dimensional Newton constant is not inserted by hand, but determined by global internal geometry:

$$G_4 = \frac{G_D}{\int_{\mathscr{M}_{\text{int}}} d^n y \sqrt{g_{\text{int}}}\, \mathscr{C}_{\text{int}}}$$

where:

- G_D= higher-dimensional gravitational constant
- $\mathscr{M}_{\text{int}}$= internal shell geometry
- g_{int}= internal metric determinant
- $\mathscr{C}_{\text{int}}$= geometric weighting factor containing curvature, topology, torsion and holonomy information.

This means gravity appears weak in four dimensions because it is controlled by a global geometric normalisation rather than a local field strength.

Dark-sector energy from averaged curvature

Effective energy densities arise from internal curvature projection:

$$\rho_4 = \frac{|\langle R_D \rangle|}{16\pi G_4}$$

where:

- ρ_4= effective four-dimensional energy density
- $\langle R_D \rangle$= averaged internal Ricci scalar curvature.

In this interpretation, dark energy and dark matter correspond to different forms of stored geometric curvature or torsion rather than new particle species.

Emergence of gauge fields

Gauge fields arise from symmetry directions of internal geometry through dimensional reduction:

$$A_\mu^a \sim g_{\mu i} K^{ai}$$

where:

- K^{ai} are Killing vectors generating internal symmetries
- $g_{\mu i}$ are mixed metric components linking spacetime and internal directions.

This shows that gauge bosons emerge from geometry itself.

Curvature capacity and the limits of spacetime

General relativity treats spacetime as a flexible geometric medium that can curve in response to matter and energy. The shell framework adds a further possibility: Lorentzian spacetime may also possess a finite capacity to sustain curvature before a deeper geometric description becomes necessary. A natural invariant measure of total curvature is

$$\mathscr{C}_{\mathscr{M}} = \int_{\mathscr{M}} R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \sqrt{-g}\, d^4x$$

where $R_{\mu\nu\rho\sigma}$ is the spacetime curvature tensor and $\mathscr{C}_{\mathscr{M}}$ measures the integrated curvature content of the manifold.

This quantity is fully coordinate-independent and captures both matter-supported curvature and free gravitational curvature, such as tidal distortions around compact objects.

At one extreme, as $\mathscr{C}_{\mathscr{M}} \to 0$, spacetime approaches the flat Minkowski limit. At the other, in regions of extreme curvature such as black-hole interiors, Lorentzian geometry may cease to provide a complete effective description. Instead of terminating in a singularity, spacetime could undergo a transition to a deeper Riemannian geometric phase lying beneath the familiar causal structure of relativity.

In this picture, black holes become potential laboratories for testing where classical spacetime ends and more fundamental geometry begins.

Surface projection and hidden meaning of Kaluza–Klein theory

Traditional Kaluza–Klein reduction is usually described as compactification. In the shell framework it has a deeper interpretation: it is also a **surface projection mechanism**, where observable fields arise from symmetry structure on internal geometric boundaries rather than from bulk curvature alone.

Vacuum energy without fine tuning

The cosmological constant problem arises because quantum field theory predicts a vacuum energy density vastly larger than what is observed. In the shell framework, this mismatch is avoided by recognising that vacuum energy is geometric, not local.

Vacuum energy does not originate from summing field zero-point energies. Instead, it reflects residual curvature stored in internal shells. A key mathematical result is that when curvature is projected from higher shells into spacetime, explicit dependence on internal length scales cancels. The result is a finite effective energy density set by geometry, not by arbitrary cutoffs.

This cancellation removes the need for fine tuning without introducing new dynamical mechanisms.

A cyclic Universe without singularities

If dark energy arises from slow geometric relaxation, it cannot persist indefinitely. As curvature channels exhaust, spacetime approaches a state of vanishing energy density. In the shell framework, this leads not to a singularity but to a phase transition. The Big Bang is reinterpreted as a transition from a pregeometric symmetry-dominated state into a geometric spacetime phase. Energy is not destroyed or created; it is reorganised between latent symmetry and realised curvature. This allows for a cyclic cosmology without violating conservation laws or introducing speculative bounce dynamics.

While the effective four-dimensional energy density tends to zero at the end of each cycle, the underlying internal geometry is not erased. Volume-projected geometric structure persists across cycles, carrying memory even when its spacetime energy projection vanishes.

Within this framework, the present Universe corresponds to an early phase of a much longer geometric cycle, with cosmic time placing us roughly 14 billion years into a longer geometric cycle, with illustrative model estimates of order 96 billion years depending on parameter choice. Importantly, any signatures of previous cycles would not appear as direct observables, but could instead manifest indirectly through large-scale geometric correlations or statistical deviations from standard cosmological expectations. Cyclicity is structural, not phenomenological.

Observational consistency, not reinvention

The shell framework is intended to remain broadly compatible with ΛCDM phenomenology at current observational precision. It does not attempt to replace the standard model of cosmology, but to reinterpret its components geometrically. Small anomalies in the cosmic microwave background, large-scale correlations, or the detailed evolution of the dark-energy equation of state may eventually offer tests of this interpretation. For now, the framework emphasises consistency with established observations, while also suggesting potential avenues for future tests.

These include possible deviations from standard cosmological correlations at the largest observable scales, as well as strong-field signatures associated with curvature-dependent transitions in black holes, which may in principle leave observable imprints in gravitational-wave signals or black-hole evolution.

A geometric perspective

At its core, the geometric shell framework suggests a shift in perspective. Rather than asking what new entities fill the Universe, it asks how geometry itself organises physical emergence. Gravity arises when spacetime acquires causal structure; fields arise when internal geometry supports gauge connections; dark matter and dark energy may arise when geometry stores effective energy without producing conventional fields. In this view, the Universe may be understood less as a collection of separate substances and more as physical structure emerging from organised geometry.

Whether nature uses such an internal geometric hierarchy remains an open question, but the framework illustrates how familiar physical sectors might emerge from a common mathematical origin.

Relation to String Theory and Higher-Dimensional Frameworks

Rather than treating strings as primitive entities, the Shell Model suggests they may arise as effective descriptions of constrained geometric dynamics in compact internal sectors. The emphasis therefore shifts from objects to structure: from strings themselves to the geometry that gives rise to string-like behaviour.

The author used ChatGPT (OpenAI) for assistance with drafting and editorial preparation of this article. A detailed mathematical development of the shell framework, has been archived on Zenodo as technical monograph and research manuscript versions.

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