Gravitation Without Mass: A Geometric Pressure Interpretation of Curvature

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Abstract

The classical statement that "mass curves spacetime" is widely used as an explanatory shortcut in General Relativity, yet it fails under strict ontological and operational analysis. Mass is a relational quantity that cannot be defined for an isolated object; therefore it cannot serve as the fundamental source of gravity. Using the ADM formulation, the gravitational acceleration can be written as the orthogonal projection of the curvature gradient, a structure formally equivalent to a pressure gradient. This geometric fact allows gravity to be reinterpreted as a form of *geometric pressure* acting on the compact volume that an object displaces in the spacetime manifold. The resulting framework preserves all equations of General Relativity while eliminating the conceptual inconsistencies associated with pointlike mass sources, clarifying the classical–quantum transition, and avoiding unnecessary quantization of the metric. This reinterpretation does not unify gravity with the gauge forces, but it resolves a longstanding conceptual tension by replacing mass with volume as the ontological quantity that couples matter to geometry.

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1 Gravitation Without Mass: The Failure of the Classical Mass Concept

1.1 Introduction

General Relativity asserts that *mass curves spacetime*. This statement, repeated endlessly in introductory texts, sounds intuitive at first glance. Yet, when examined rigorously, it conceals a fundamental problem: **mass is not an ontologically definable quantity in the absence of external references**.

In parallel, the ADM formalism shows that the gravitational acceleration experienced by a non-inertial observer can be written as **the orthogonal projection of the curvature gradient** onto the 3+1 foliation. Although this technical detail seldom receives attention in popular accounts, its physical significance is profound: gravity behaves exactly like a **pressure gradient**.

This observation, simple yet commonly overlooked, highlights a conceptual tension within the classical framework: if gravity can be formulated as a geometric pressure *and* mass lacks absolute definition, is it not more coherent to abandon the mass→curvature linkage and describe gravity directly as the response of the geometric medium to the **volume** displaced by an object?

The analysis that follows leads to the following conclusion:

> **Mass cannot serve as the ontological source of gravity. Volume can. Gravity is not a “force” caused by mass, but the geometric pressure generated by the curvature gradient.**

The result is fully compatible with General Relativity, but it changes its physical interpretation and removes the conceptual barrier separating the classical and quantum regimes.

1.2 The Orthogonal Projection of the Curvature Gradient

In the ADM formalism, the acceleration perceived by an observer stationary with respect to the temporal foliation is expressed as

$$a_i = D_i \ln N, \tag{1}$$

where N is the *lapse*. This term appears precisely as a **projected gradient**.

Mathematically, one may write

$$\vec{g} \equiv \Pi_\perp(\nabla R[g]), \tag{2}$$

where $R[g]$ is an appropriate curvature scalar and $\Pi_\perp$ is the orthogonal projector onto the spatial hypersurface.

This expression is not an analogy but a geometric identity derived from the 3+1 formulation. From a physical standpoint, it is indistinguishable from a pressure gradient:

$$\vec{g} \sim -\nabla P_{\text{geom}}. \tag{3}$$

Geometry behaves like an elastic medium. If that medium is more "tense" (higher curvature) in one region than in another, an effective pressure arises that pushes objects. No "mass" is needed—only **geometric variation**.

This formulation of gravity contains an implicit message that is rarely stated explicitly: gravity **does not require** the existence of something called "mass" in order to operate.

1.3 The Logical Problem of Mass

Here the central question emerges:

1.3.1 Can mass be defined if only one object exists in the universe?

Within the traditional framework, the strict answer is:

No.

The reason is elementary:

- In Newtonian mechanics, mass is measured by comparison with another mass. With only one object, no comparative dynamics exist.
- In General Relativity, mass is a *relational* contribution to the energy–momentum tensor, which only acquires meaning when fields and observers are present. A lone object does not furnish an operational definition.
- In the Standard Model, mass arises from field couplings, yet its measurement still requires external reference.

Thus, speaking of "mass" without an environment is equivalent to speaking of "velocity without a reference point," which has no physical meaning.

1.3.2 Immediate deduction:

> **Mass is relational, not absolute. It cannot be the ontological foundation of gravity.**

This assertion does not contradict traditional physics; it simply exposes a conceptual inconsistency that has remained a historical taboo.

1.4 By Contrast, Compact Volume *Is* Definable Even for a Single Object

Here the key conceptual shift occurs:

> **Volume does not require external reference.**

- It is intrinsic.

- It is geometric.
- It is definable even if the universe contains only one object.

This makes volume the true ontological candidate for describing how an object interacts with the geometric medium.

If a medium exerts pressure, that pressure necessarily acts on **volume**, not on "mass." There is no physical phenomenon in which a pressure acts on something that occupies no volume.

2 Gravity as Geometric Pressure

2.1 From Curvature to Pressure: The Conceptual Transition

From the ADM formalism we have already seen that:

$$\vec{g} \equiv \Pi_{\perp}(\nabla R[g]) \sim -\nabla P_{\text{geom}}. \tag{4}$$

This compact equation allows one to rewrite gravitational dynamics without ever mentioning the word 'mass'.

The logic is direct:

1. Curvature measures the local deformation of the geometric medium.
2. The gradient of that curvature indicates the direction in which the deformation changes.
3. The orthogonal projection selects the component that affects the motion of an observer in 3D.
4. The resulting expression has exactly the same formal structure as the pressure gradient in a fluid.

And all pressure acts on volume.

In classical, quantum, or relativistic physics, pressure never acts on "mass": it acts on *surface*, producing acceleration on whatever occupies volume.

From this, the physical equivalence emerges:

> **Gravity is the geometric pressure generated by curvature gradients. Its fundamental source is not mass, but the volume an object displaces in the geometric medium.**

2.2 What Happens If One Takes This Interpretation Seriously

An immediate consequence follows:
The famous statement "mass curves spacetime" is circular, because:

1. Mass cannot be defined for an isolated object.
2. Curvature *can* be defined (it is a property of geometry).
3. Volume *can* be defined (it is an intrinsic property of the object).
4. Geometric pressure acts on volume, not on mass.

Therefore, even within the traditional framework, the correct statement should be:

> **The volume of an object induces deformations in the geometric medium, and the resulting pressure is what we call gravity.**

This does not contradict any Einstein equation, but it does eliminate the historically inherited Newtonian interpretation.

2.3 Consequences for Conventional Approaches to Quantum Gravity

Traditional attempts to quantize gravity rest on a core assumption:

> **"Mass is pointlike and produces pointlike curvature.**
> **Quantizing gravity means quantizing that curvature."**

But if mass is a relational concept and cannot be defined in the one-object limit:

- you cannot associate a universal mass operator,
- you cannot define "pointlike mass" as a quantum source,
- you cannot construct a graviton coupled to something that is not ontologically stable.

This undermines the standard approach at a foundational level.
In contrast, if the origin of gravity is:

$$\text{gravity} = \text{geometric pressure acting on volume}, \tag{5}$$

then:

1. Volume is definable in the quantum regime (effective spatial occupation of the wavefunction).
2. Geometric pressure depends on variations of curvature, which form a continuous field.
3. No conceptual discontinuity exists between classical and quantum descriptions.
4. A graviton as an independent quantization of spacetime is unnecessary.

Conclusion: the classical–quantum barrier dissolves effortlessly once mass is abandoned as the fundamental source.

2.4 And Yet... This Does *Not* Unify the Gauge Forces

- Electromagnetic, weak, and strong interactions arise from **internal symmetries** of quantum fields.
- They do not depend on displaced geometric volume.
- They do not act as pressures on a medium, but as gauge interactions grounded in internal phases.

Therefore:

> **This approach does not unify the gauge forces. It provides only a unified geometric interpretation of gravity.**

Far from being a weakness, this strengthens the argument: we are not proposing a theory of everything, but a conceptual clarification that resolves an inconsistency present since 1916.

2.5 The Final Result: What Remains of "Mass" Is a Relational Epiphenomenon

After the entire development, the synthesis is:

1. Mass cannot be defined without external reference.
2. It cannot serve as an ontological foundation.
3. Geometry produces pressure when curvature gradients are present.
4. That pressure acts on the volume an object occupies.
5. Gravity is that interaction, not a force caused by mass.

In other words:

> **Mass does not curve spacetime.**
> **Volume sits within a medium whose geometric pressure depends on curvature.**
> **Gravity is that pressure.**

3 Extended Discussion

3.1 How This Reinterpretation Fits with Classical Intuition

The general public—and many physicists—grow up with the familiar image of Einstein drawing a rubber sheet on which a "mass" creates a depression and thereby generates gravity.

That image contains two profound flaws:

1. **It introduces mass as the primary cause**, even though mass cannot be defined without a second object to serve as reference.

2. **It conflates curvature with "material deformation"**, which is not physically literal.

The reinterpretation developed here corrects both issues without altering any known equation.

3.1.1 What Replaces Mass in This New View?

An attribute that *is* definable for an isolated object:

the object's compact volume.

This volume interacts with a geometric medium characterized by:

- its curvature,
- its curvature gradient,
- its capacity to generate effective pressure.

By analogy, a quantum submarine floating in a completely empty ocean **would still possess volume**, even if nothing else existed. It would have no "mass," because there would be no reference with which to measure inertia, but its volume would determine how the medium exerts pressure on it if the "ocean" exhibited variations in tension.

3.1.2 Classical Intuition Reordered

If one teaches the public:

"Gravity is the pressure exerted by space when its curvature changes,"

one avoids the circularity of "mass curves spacetime," which in strict terms means:

- Mass creates curvature,
- Curvature creates gravity,
- Gravity defines inertial mass,
- Inertial mass determines dynamics.

A logical circle that collapses instantly the moment one asks about a universe containing only a single object.

4 Implications for General Relativity

Nothing presented here contradicts Einstein's equations. Rather, it reveals something that was always present but never explicitly interpreted.

4.1 The Energy–Momentum Tensor Is Relational

The term “mass” always appears as a component of the tensor $T_{\mu\nu}$. But this tensor:

- does not define mass by itself,
- requires an observer,
- requires a 3+1 decomposition,
- and in the limit of a single object, loses any operational meaning.

In contrast, the curvature $R[g]$, its gradient, and their projections are purely geometric concepts.

4.2 Einstein’s Equation Remains Intact

$$G_{\mu\nu} = 8\pi T_{\mu\nu} \tag{6}$$

but the interpretation shifts:

- The left-hand side is geometry.
- The right-hand side does not represent “mass,” but *the manner in which matter occupies space and energizes fields.*
- The observable physical response (gravity) arises when geometry is projected onto the volume displaced by an object.

This reading fits naturally within General Relativity; it does not modify it.

5 Implications for Quantum Physics

Here an unexpected benefit emerges.
Traditional attempts to merge gravity with quantum mechanics fail for a deep reason:

1. They attempt to quantize the metric.
2. They introduce gravitons coupled to “pointlike mass.”
3. But pointlike mass cannot be defined without multiple objects.
4. The entire framework becomes conceptually unstable.

If gravity is understood as:

$$\text{geometric pressure} = \Pi_{\perp}(\nabla \text{curvature}), \tag{7}$$

then:

5.0.1 Quantum Volume Is Definable

The effective spatial extent of a particle (probability distribution, Compton wavelength scale, quantum localization) is measurable and meaningful even in isolation.

5.0.2 Geometric Pressure Does Not Require Quantizing the Metric

Because:

- there is no "Newtonian force" to quantize,
- there is no pointlike source,
- there is no ontological need for gravitons.

Pressure is an *effect* of the geometric medium, just as the wavefunction is an effect of the quantum medium.

5.0.3 The Quantum–Classical Continuity Emerges Naturally

Once gravity stops depending on "mass" and instead depends on "volume under geometric pressure," the classical discontinuity disappears. Quantum volume couples naturally to geometry without requiring pointlike singularities.

6 Why This Result Does *Not* Unify the Gauge Forces

- The gauge forces U(1), SU(2), and SU(3) depend on internal symmetries of quantum fields.
- They have no relation to displaced geometric volume.
- They cannot be derived from geometric pressure, since they act not on volume but on internal charges.

Therefore:

> **Gravity can be reinterpreted as pressure, but this does not imply that electromagnetism or the weak/strong interactions can be unified with it through the same mechanism.**

7 Putting the Core Idea in Plain Words

1. Mass is a concept that requires comparison; without other objects, it does not exist.
2. Volume does exist even if you are alone in the universe.
3. Spacetime geometry can exert pressure when its curvature changes.

4. That pressure pushes objects that occupy volume.
5. That push is what we call gravity.
6. Gravity is not produced by mass; it is produced by volume interacting with geometric pressure.

8 Formal Conclusion

The development presented here demonstrates that the traditional formulation "mass curves spacetime" does not withstand strict ontological and operational scrutiny. Mass is a relational quantity, dependent on external comparisons and on the presence of multiple objects or a reference field. In a universe composed of a single object, mass lacks physical definability.

In contrast, an object's compact volume is an intrinsic property, definable even in isolation. When gravitational acceleration is expressed through the orthogonal projection of the curvature gradient in the ADM formalism, one obtains a term structurally equivalent to a pressure gradient. This fact, arising solely from geometry, allows gravity to be reinterpreted as **geometric pressure** acting on the object's volume.

This reinterpretation leaves the equations of General Relativity unchanged, but substantially modifies the physical interpretation of gravitational interaction:

- It does not depend on mass, but on volume.
- The need to quantize the metric as an independent field disappears.
- The transition between the classical and quantum regimes becomes conceptually continuous.
- No unification with gauge forces is produced, and that lack of unification ceases to be a conceptual problem.

Taken together, these conclusions suggest that a long-standing line of geometric unification based on mass as a fundamental source is conceptually misguided, and that a more coherent alternative is to regard gravity as the response of the geometric medium to displaced volume.

9 Author's Note

The interpretation that emerges from this analysis does not seek to replace General Relativity, but rather to **restore conceptual order** where inherited tradition has maintained ambiguity. From a mathematical standpoint, gravity already possessed the structure of geometric pressure hidden within the ADM projection. From a philosophical standpoint, mass was never an absolute property. From a quantum standpoint, the conceptual transition becomes natural only when pointlike masses are replaced by effective volumes subjected to geometric pressure.

The result is a cleaner, more coherent framework that is more compatible with modern physics:

> **gravity is an emergent property of geometry when geometry exerts pressure on volumes, not a force caused by masses.**

10 Bibliography

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