Parsimony, Ontology, and Effective Descriptions of Gravitation

Carlo Mancosu[1,2]

[1]*Kitzanos Società Cooperativa, Cagliari, Italy*
[2]*BFLOWS Fintech Innovation*
carlo.mancosu@kitzanos.com

February 2026

Abstract. Arguments from parsimony are frequently invoked in discussions of alternative formulations of gravity, yet the criterion is often reduced to a narrow accounting of fields, parameters, or Lagrangian terms. This paper argues that such local measures of simplicity are inadequate and potentially misleading. A more appropriate notion of parsimony—one that accords with the historical development of physics—concerns the minimization of independent ontological categories required to describe natural phenomena across all domains. From this perspective, the standard geometric interpretation of General Relativity, which assigns spacetime curvature a unique ontological status not shared by any other interaction, introduces conceptual fragmentation into the descriptive framework of physics. A constitutive reformulation employing propagation-response fields, by contrast, adopts the same formal grammar already used in optics, elasticity, hydrodynamics, and analogue gravity systems. This shift does not introduce new entities but changes the level of description, thereby achieving greater global parsimony. The analysis suggests that the choice between geometric and constitutive interpretations cannot be adjudicated by appeals to simplicity in the narrow sense, and that arguments for geometric fundamentality require justification beyond parameter counting.

Keywords: parsimony, ontological parsimony, General Relativity, constitutive fields, effective field theory, philosophy of physics

1. Introduction

In discussions of alternative formulations of gravity, appeals to parsimony occupy a prominent rhetorical position. The standard geometric interpretation of General Relativity is frequently defended on grounds of simplicity: the Einstein-Hilbert action contains few parameters, the field equations are determined by minimal assumptions, and the theory requires no additional fields beyond the metric tensor. Any reformulation introducing additional mathematical structure appears, on this accounting, to violate Occam's razor.

This paper argues that such arguments rest on a conceptually inadequate notion of parsimony. The criterion invoked—which we may call *local parsimony*—concerns the number of symbols, parameters, or degrees of freedom appearing in a single theoretical formulation. While not without value, this criterion proves insufficient and frequently misleading when applied to foundational questions in physics. The history of theoretical physics reveals a different pattern: progress has consistently favored what we term *global parsimony*, the minimization of independent ontological categories required to describe phenomena across all domains of physics.

The distinction matters because General Relativity, under its standard interpretation, assigns gravity a unique ontological status. Spacetime geometry is taken as fundamental; curvature is primitive; matter inhabits a geometric stage. No other interaction in modern physics receives analogous treatment. Electromagnetism, the weak and strong forces, condensed matter systems, and statistical ensembles are all described within a common framework of fields, local responses, and effective media. Gravity alone stands outside this unifying grammar.

This conceptual exceptionalism is not forced by experiment. As we shall argue, all classical gravitational tests constrain operational relations—clock rates, light propagation, particle trajectories—without uniquely determining the ontology underlying these relations. The same empirical content admits formulation in terms of constitutive response fields governing signal propagation. Such a reformulation does not introduce new substances or hidden sectors; it adopts the descriptive strategy already employed throughout physics.

The paper proceeds as follows. Section 2 articulates the distinction between local and global parsimony and argues that historical precedent favors the latter. Section 3 examines the special ontological status accorded to geometry in the standard interpretation of General Relativity. Section 4 analyzes what gravitational experiments actually measure and the extent to which they constrain ontological interpretation. Section 5 explains how constitutive descriptions avoid the introduction of new entities. Section 6 draws out the implications for parsimony assessment. Section 7 offers concluding remarks.

2. Local and Global Parsimony

The principle of parsimony admits multiple interpretations, and clarity regarding these distinctions is essential for evaluating competing theoretical frameworks. We distinguish two fundamentally different applications of the principle.

Local parsimony concerns the internal economy of a single theoretical formulation. By this measure, a theory is simpler if it contains fewer parameters, fewer fields, fewer terms in its Lagrangian, or fewer independent equations. Local parsimony is essentially a bookkeeping exercise: one counts mathematical objects and prefers formulations with smaller inventories.

Global parsimony concerns the conceptual resources required to describe nature as a whole. By this measure, a theoretical framework is simpler if it requires fewer independent ontological categories—fewer fundamentally distinct kinds of entities, interactions, or structures—to account for the full range of physical phenomena. Global parsimony is an exercise in conceptual unification: one identifies the minimal set of primitive notions from which diverse phenomena can be understood.

These criteria can yield opposing verdicts. A formulation that appears more complex by local standards may achieve greater simplicity globally if it eliminates a conceptual category that would otherwise require independent postulation.

The history of physics provides instructive illustrations. Consider the transition from Newtonian gravity to Maxwell's electromagnetism. Newton's gravitational theory is locally simpler by nearly any accounting: forces act instantaneously at a distance, the potential is scalar, and the mathematical apparatus is minimal. Maxwell's electromagnetism introduces vector fields pervading all space, additional degrees of freedom, gauge structure, and wave dynamics. By local standards, Maxwell's theory is unambiguously more complicated.

Yet physics accepted Maxwell's framework precisely because it achieved greater global simplicity. The Newtonian concept of action at a distance constitutes an ontological category sui generis—forces that propagate instantaneously across arbitrarily large distances without any intervening medium or mechanism. Maxwell's field ontology, while locally more elaborate, eliminates this exceptional category by describing electromagnetic interactions through the same local field propagation that appears elsewhere in physics. The gain in global uniformity outweighs the cost in local complexity.

A similar pattern characterizes the acceptance of special relativity. Lorentz's ether theory and Einstein's special relativity yield identical predictions for all electromagnetic phenomena. The theories are empirically equivalent within their domain of application. Lorentz's formulation preserves Newtonian absolute time and space while introducing compensating dynamical effects (length contraction, time dilation) that conspire to make the ether undetectable. Einstein's formulation eliminates the ether entirely by revising the conceptual foundations of space and time.

From the standpoint of local parsimony, Lorentz's theory has certain advantages: it preserves familiar spatial and temporal concepts and introduces no radical revision of kinematics. From the standpoint of global parsimony, Einstein's theory is superior: it eliminates an undetectable ontological category (the ether) along with the conceptual awkwardness of dynamical effects perfectly calibrated to hide its presence.

The pattern admits generalization. Progress in theoretical physics has consistently involved accepting greater local complexity in exchange for reduced global fragmentation. Statistical mechanics introduces the elaborate apparatus of phase space, probability distributions, and ergodic theory—locally more complex than phenomenological thermodynamics—but achieves global parsimony by reducing thermal phenomena to mechanics. Quantum field theory introduces renormalization, gauge redundancy, and infinite-dimensional Hilbert spaces, yet achieves unification across particle physics that would otherwise require ad hoc phenomenological parameters.

The lesson is that parsimony arguments in physics must attend to the appropriate level of description. Counting parameters or fields within a single theory provides at best a partial guide; the more fundamental question concerns the number of independent conceptual categories required across physics as a whole.

3. The Special Ontological Status of Geometry

Modern physics employs a remarkably uniform descriptive language across its diverse domains. Quantum field theory, condensed matter physics, statistical mechanics, and classical field theory share a common conceptual vocabulary: fields, local interactions, effective responses, emergent collective behavior. This uniformity is both a practical convenience and, arguably, a reflection of genuine structural features of physical reality.

General Relativity, under its standard interpretation, represents an exception to this uniformity. The theory is typically understood not as describing a field in spacetime but as describing spacetime itself. The metric tensor $g_{\mu\nu}$ is not interpreted as a field propagating on a background manifold; rather, it *constitutes* the geometric structure of spacetime. Curvature is not a derived property of some underlying medium; it is ontologically primitive. Matter does not interact with a gravitational field in the same sense that charged particles interact with the electromagnetic field; rather, matter moves along geodesics of a curved geometry that matter itself sources.

This interpretive stance assigns gravity a unique ontological role. In electromagnetism, we distinguish the field $F_{\mu\nu}$ from the spacetime on which it propagates. In gravity, this distinction collapses: the field *is* the geometry. The formal apparatus may resemble other field theories, but the conceptual status differs fundamentally.

Several consequences follow from this geometric interpretation:

First, gravity becomes categorically distinct from all other interactions. The electromagnetic, weak, and strong forces are described as field excitations on spacetime; gravity is identified with spacetime structure itself. This categorical distinction has no obvious empirical counterpart—all interactions manifest through their effects on observables—but it introduces a fundamental asymmetry into the ontological scheme of physics.

Second, the geometric interpretation resists unification with quantum mechanics at a conceptual level, quite apart from technical difficulties. Quantum field theory treats fields as operators on a Hilbert space, with the spacetime manifold providing a fixed background structure. If gravity *is* spacetime geometry, then quantizing gravity requires quantizing the arena within which quantum theory itself is formulated. The conceptual circularity is not merely technical; it reflects the special ontological status that the geometric interpretation assigns to gravity. The effective field theory approach to quantum gravity treats the metric as a field like any other, amenable to standard quantization techniques at low energies, but this pragmatic stance sits uneasily with the claim that geometry is ontologically fundamental.

Third, the geometric interpretation makes gravity ontologically exceptional in a way that other effective descriptions are not. We do not interpret the permittivity of a dielectric medium as revealing fundamental features of reality; we recognize it as an effective parameter emerging from underlying dynamics. The geometric interpretation of gravity, by contrast, treats curvature as primitive rather than emergent.

It is essential to recognize that this interpretive choice is not mandated by General Relativity's empirical success. The mathematical formalism of the theory—the field equations, the geodesic equation, the predictions for observable quantities—does not determine whether the metric represents fundamental geometry or effective propagation properties. The same equations admit both readings.

Nor is the geometric interpretation forced by theoretical elegance. The Einstein-Hilbert action $S = \int R\sqrt{-g}, d^4x$ is undeniably beautiful, but its beauty does not discriminate between geometric and constitutive readings. The action describes how the metric responds to matter; it does not legislate the metric's ontological status.

The question, then, is whether the conceptual exceptionalism inherent in the geometric interpretation is justified. Does gravity merit a unique ontological category, or might the appearance of geometric fundamentality reflect a particular level of description rather than ultimate physical reality?

4. What Gravitational Experiments Measure

The empirical case for General Relativity rests on an impressive array of precision tests spanning solar system scales, binary pulsar systems, gravitational wave detection, and cosmological observations. These tests have confirmed the theory's predictions with extraordinary accuracy, in some cases to parts in 10^5. The question we now address is what, precisely, these experiments establish.

All classical gravitational tests measure operational relations among physically accessible quantities. The Pound-Rebka experiment measures the frequency shift of photons traversing a gravitational potential difference. The Shapiro delay measures the additional time required for electromagnetic signals to propagate near massive bodies. Light deflection experiments measure the angular deviation of photon trajectories. Perihelion precession measurements track the secular advance of planetary orbits. Gravitational wave detectors measure differential length changes induced by passing radiation.

In each case, the observable quantity is a relation among operationally defined entities: clock readings, light travel times, angular positions, interferometer phases. What the experiments constrain is the structure of these relations—how clocks run at different locations, how light propagates through gravitating regions, how test particles follow curved paths.

The crucial observation is that these operational relations do not uniquely determine the ontology underlying them. Consider gravitational redshift. The observed frequency shift $\Delta\frac{\nu}{\nu} = \Delta\frac{\Phi}{c^2}$ depends on the potential difference $\Delta\Phi$ between emission and absorption points. The measurement constrains the functional relationship between frequency and gravitational potential. It does not determine whether Φ represents a feature of geometric structure or a property of a propagation medium.

The same underdetermination applies to all classical tests. The parametrized post-Newtonian formalism encodes the empirical content of weak-field gravity in a set of dimensionless parameters (γ, β, and others) that characterize observable relations. General Relativity predicts specific values for these parameters ($\gamma = \beta = 1$), and experiments confirm these predictions with high precision. But the PPN formalism is deliberately agnostic about ontological interpretation; it constrains how observables relate without specifying what entities generate those relations.

This situation exemplifies a familiar pattern in the philosophy of science: empirical equivalence does not entail ontological uniqueness. When two theoretical frameworks generate identical predictions for all operationally accessible observables within a tested regime, the choice between them involves considerations beyond empirical adequacy.

Consider a concrete alternative. Instead of interpreting the metric $g_{\mu\nu}$ as encoding geometric structure, one may interpret gravitational effects as arising from constitutive response fields χ and ψ governing temporal and spatial signal propagation respectively. In the appropriate limit, such a formulation reproduces the standard post-Newtonian phenomenology exactly. The operational predictions —clock rates, light bending, perihelion precession—are identical. The experiments cannot distinguish between geometric and constitutive ontologies.

This is not a deficiency of current measurements awaiting resolution by future technology. The underdetermination is structural: operational relations constrain how observables behave without uniquely specifying the nature of the entities producing that behavior. The same measurement outcomes are compatible with both geometric and constitutive interpretations because both interpretations respect the same relational structure. The explicit mapping between constitutive response fields and standard PPN parameters is developed in Appendix A.

The point generalizes beyond specific experimental tests. The empirical success of General Relativity establishes that gravitational phenomena respect certain structural regularities—the relational structure encoded in the field equations and their solutions. It does not establish that these regularities reflect geometric properties of spacetime rather than propagation characteristics of an underlying medium.

5. Constitutive Descriptions and Ontological Economy

If constitutive formulations represent merely terminological variants of geometric descriptions, they would hold little philosophical interest. This section argues that constitutive descriptions achieve genuine ontological economy by adopting a uniform mode of explanation already employed across physics, without introducing new entities.

A constitutive formulation of gravitational effects employs propagation-response fields—scalar functions $\chi(x)$ and $\psi(x)$ governing temporal and spatial signal speeds—to describe how electromagnetic and matter signals propagate through gravitating regions. The effective metric emerges from these response functions:

$$ds^2 = -c^2\chi^2 dt^2 + \psi^2(dx^2 + dy^2 + dz^2) \tag{1}$$

In the weak-field limit with appropriate boundary conditions, this formulation reproduces all classical gravitational phenomenology.

Critics might object that introducing χ and ψ adds to the ontological inventory. The objection, however, fundamentally misconstrues the nature of constitutive parameters. Response fields are not additional substances requiring independent existence; they are coarse-grained descriptors of collective behavior, exactly as the permittivity $\varepsilon(\omega)$ in electromagnetism or the elastic moduli K, G in continuum mechanics are not new entities in matter theory. No one proposes that Young's modulus is a substance; it is a phenomenological coefficient encoding how materials respond to stress. The gravitational response fields χ and ψ occupy precisely the same conceptual role.

This mode of description pervades physics. In electromagnetic theory of continuous media, permittivity ε and permeability μ characterize field propagation without constituting new ontological categories. In elasticity, elastic moduli describe mechanical response; in hydrodynamics, viscosity and pressure fields emerge from molecular dynamics. In each case, constitutive parameters are effective descriptors, not fundamental entities.

The analogue gravity program provides particularly compelling evidence. Curved spacetime metrics emerge from perturbation propagation in fluid flows, Bose-Einstein condensates, and other media. The effective geometry governs signal propagation, yet no one interprets these systems as discovering fundamental geometric structure. Geometric phenomenology can arise without geometric ontology.

The scalar-tensor formalism provides a particularly instructive comparison. In these theories, gravity is mediated by both a metric tensor and one or more scalar fields, with the relative contribution determined by coupling functions. The Damour-Esposito-Farèse framework shows that such theories can reproduce all Solar System tests while differing from General Relativity in strong-field or cosmological regimes. The scalar field is not interpreted as an additional substance but as an additional degree of freedom in the gravitational sector—a descriptive refinement, not an ontological multiplication.

The constitutive reading is fully compatible with the standard effective field theory treatment of gravity as a low-energy field sector. From the EFT perspective, General Relativity represents the leading-order behavior of a more complete theory, with corrections suppressed by powers of the Planck scale. The response fields χ and ψ provide an alternative parametrization of this low-energy sector, one that makes explicit the propagation structure without prejudging ontological commitments.

The contrast with the geometric interpretation is instructive. If spacetime curvature is ontologically fundamental, then gravity requires a conceptual category—dynamic geometry—not employed elsewhere in physics. The constitutive formulation employs only the category of effective medium response, which physics already uses for electromagnetic, acoustic, and mechanical phenomena. This is a change of descriptive level, not an ontological multiplication. The result is not a larger ontology but a more uniform one.

6. Implications for Parsimony Assessment

We are now positioned to assess the relative parsimony of geometric and constitutive interpretations by the criterion we have argued is appropriate: global ontological economy.

At the level of a single Lagrangian—the level of local parsimony—General Relativity in its standard formulation appears maximally simple. The Einstein-Hilbert action involves only the metric tensor and its curvature. Any constitutive reformulation introduces additional mathematical structure: the response fields χ and ψ, their dynamical equations, their coupling to matter. By local standards, the geometric formulation wins.

But local parsimony, we have argued, is not the appropriate measure. The relevant question is how many independent ontological categories each interpretation requires physics as a whole to employ.

The geometric interpretation requires that gravity occupy a unique conceptual category. Spacetime geometry is not an effective description emergent from underlying dynamics; it is fundamental. Curvature is not a derived property; it is primitive. This assignment places gravity outside the unifying framework that describes all other interactions.

Consider the inventory of ontological categories under the geometric interpretation:

- Fields propagating on spacetime (electromagnetic, weak, strong, matter fields)
- Effective medium responses (optics, elasticity, hydrodynamics)
- Fundamental spacetime geometry (gravity alone)

The third category appears only for gravity. It has no analogue in any other domain of physics.

The constitutive interpretation, by contrast, places gravity within the second category. Gravitational effects arise from the response of an underlying medium to stress-energy, just as optical effects arise from the electromagnetic response of matter. The constitutive parameters χ and ψ play roles analogous to the refractive index in optics or the elastic moduli in mechanics.

Under this interpretation, the inventory simplifies:

- Fields (electromagnetic, weak, strong, matter, gravitational)
- Effective medium responses (optics, elasticity, hydrodynamics, gravity)

There is no third category. Gravity no longer requires conceptual resources distinct from those employed throughout physics.

The gain in global parsimony is substantial. The constitutive interpretation achieves what we may call *ontological uniformity*: the same mode of description applies across all interactions. One need not explain why gravity alone receives geometric treatment while all other phenomena are described through fields and effective media. The awkward question—what distinguishes gravity ontologically from electromagnetism, given their formal similarities—no longer arises.

This analysis suggests a reframing of parsimony arguments in gravitational physics. The question is not whether a particular formulation minimizes parameters or terms; any reformulation can be made more or less parsimonious by such local measures. The question is whether the conceptual framework requires gravity to occupy a special ontological category or whether gravitational effects can be understood within the uniform descriptive scheme that governs the rest of physics.

By this criterion, the constitutive interpretation achieves greater parsimony. It reduces conceptual fragmentation. It eliminates an exceptional category. It employs for gravity the same explanatory strategy that succeeds everywhere else.

We emphasize that this argument establishes only a parsimony advantage, not empirical superiority. The geometric and constitutive interpretations are empirically equivalent within tested regimes. The choice between them involves theoretical virtues—parsimony among them—rather than experimental discrimination. What our analysis shows is that parsimony arguments, properly understood, favor ontological uniformity over geometric exceptionalism.

7. Concluding Remarks

We have argued that standard appeals to parsimony in gravitational physics employ an inadequate notion of simplicity. Local parsimony—minimizing parameters, fields, or Lagrangian terms—provides at best a partial guide to theoretical evaluation. The more fundamental criterion is global parsimony: minimizing the number of independent ontological categories required to describe physics as a whole.

By this criterion, the standard geometric interpretation of General Relativity incurs a significant cost. It assigns gravity a unique ontological status—fundamental spacetime geometry—not employed for any other interaction. This conceptual exceptionalism fragments the descriptive scheme of physics into domains with incompatible foundational concepts.

The constitutive reformulation achieves greater global parsimony by describing gravitational effects through propagation-response fields, the same conceptual apparatus used in optics, elasticity, and analogue gravity systems. This is not an addition to the ontological inventory but a change of descriptive level that achieves uniformity across physics.

The analysis carries implications for how we conceptualize gravity. Under the constitutive interpretation, gravity is neither a force nor curvature as substance. It is simply a sector of propagation response, formally analogous to every other effective field system. The appearance of geometric fundamentality reflects a particular interpretive choice rather than a unique feature of gravitational phenomena.

We do not claim that the constitutive interpretation is correct and the geometric interpretation false. Empirical equivalence precludes such determination within currently tested regimes. What we claim is that arguments from parsimony, when properly formulated, do not favor the geometric interpretation. Indeed, by the criterion of global ontological economy, they favor constitutive uniformity.

The choice between interpretations ultimately involves considerations beyond parsimony: fruitfulness for future research, coherence with quantum theory, naturalness of extensions to new regimes. These considerations lie beyond the scope of the present analysis. Our more limited aim has been to clarify what parsimony does and does not establish, and to argue that the geometric interpretation's apparent simplicity reflects a narrow conception of what simplicity in physics should mean.

8. Appendix A: PPN/EFT Correspondence of the Constitutive Formulation

8.1. A.1 Standard Post-Newtonian Metric

In the weak-field, slow-motion regime ($v \ll c$, $\left|\Phi\right| / c^2 \ll 1$), any metric theory of gravity admits a parametrized post-Newtonian (PPN) expansion. Using the standard PPN formalism [2], in isotropic coordinates and retaining only the terms relevant for classical Solar System tests, one may write

$$g_{00} = -1 + \frac{2U}{c^2} - 2\beta\frac{U^2}{c^4} + \mathcal{O}(\varepsilon^3), \tag{2}$$

$$g_{ij} = \left(1 + 2\gamma\frac{U}{c^2}\right)\delta_{ij} + \mathcal{O}(\varepsilon^2), \tag{3}$$

$$g_{0i} = \mathcal{O}(\varepsilon^{3/2}), \tag{4}$$

where $U(\vec{x})$ is the Newtonian potential and $\varepsilon \sim v^2/c^2 \sim U/c^2$. General Relativity corresponds to $\gamma = \beta = 1$.

The parameters γ and β control all leading weak-field observables: γ governs light propagation (deflection and Shapiro delay), while β encodes nonlinear self-interaction effects entering perihelion precession.

8.2. A.2 Constitutive Parametrization and Slip

In the propagation-response description adopted in this work, gravitational effects are encoded in two scalar response fields $\chi(\vec{x})$ and $\psi(\vec{x})$, which govern temporal and spatial signal propagation respectively. The effective metric takes the form

$$g_{00} = -(1 + 2\chi/c^2) + \mathcal{O}(\varepsilon^2), \tag{5}$$

$$g_{ij} = (1 - 2\psi/c^2)\delta_{ij} + \mathcal{O}(\varepsilon^2). \tag{6}$$

We define the gravitational slip parameter

$$\eta \equiv \frac{\psi}{\chi}. \tag{7}$$

Comparison with the PPN expansion shows that, to first post-Newtonian order,

$$\gamma = \frac{\psi}{\chi} = \eta, \tag{8}$$

up to the conventional identification $\chi = \psi = -\Phi_N$ in the GR limit.

Hence Solar System bounds on γ directly translate into bounds on slip, independently of any geometric interpretation. The Cassini constraint $|\gamma - 1| < 2.3 \times 10^{-5}$ (two-way Shapiro delay) [3] becomes equivalently a constraint $|\eta - 1| < 2.3 \times 10^{-5}$ on the ratio of response fields. All current Solar System constraints are constraints on the functional behavior of response fields, not on geometric ontology.

8.3. A.3 Classical Observables in Response Variables

Expressed in terms of $\gamma = \eta$, the leading observables read:

Light deflection.

$$\Delta\theta \approxeq (1+\gamma)\frac{GM}{c^2 b} = (1+\eta)\frac{GM}{c^2 b}. \tag{9}$$

Shapiro time delay.

$$\Delta t_{\text{Shapiro}} \propto (1+\gamma)\frac{GM}{c^3} = (1+\eta)\frac{GM}{c^3}. \tag{10}$$

Gravitational redshift.

$$\frac{\Delta\nu}{\nu} \approxeq \frac{\Delta U}{c^2}, \tag{11}$$

which depends only on g_{00} and therefore constrains the temporal response χ.

Perihelion precession.

$$\Delta\phi \approxeq \frac{6\pi GM}{c^2 a(1-e^2)} \cdot \frac{2-\beta+2\gamma}{3}. \tag{12}$$

Hence the full weak-field phenomenology depends only on the combinations (ψ/χ) and on the nonlinear temporal response entering β.

8.4. A.4 Effective Field Theory Interpretation

From the effective field theory viewpoint, deviations from GR arise from additional modes or higher-dimension operators suppressed by a characteristic scale Λ:

$$S_{\text{eff}} = \frac{M_{\text{Pl}}^2}{2}\int \sqrt{-g}R\, d^4x + \int \sqrt{-g}\mathcal{L}_{\text{matter}}\, d^4x + \sum_{n\geq 2}\frac{c_n}{\Lambda^{2n-2}}\mathcal{O}_{2n}. \tag{13}$$

At energies $E \ll \Lambda$, these corrections decouple, yielding the GR limit.

In constitutive variables this decoupling manifests as

$$\eta = \frac{\psi}{\chi} \to 1 \quad \text{for} \quad g \gg a_0, \tag{14}$$

so that $(\gamma, \beta) \to (1,1)$ and all PPN tests are automatically satisfied.

The empirical content of the weak-field regime therefore constrains only the functional behavior of (χ, ψ), not their ontological interpretation as geometry or response.

9. References

[1] A. Einstein, "Die Feldgleichungen der Gravitation," *Sitzungsberichte der Preussischen Akademie der Wissenschaften*, 844–847 (1915).

[2] C. M. Will, "The Confrontation between General Relativity and Experiment," *Living Reviews in Relativity* **17**, 4 (2014).

[3] W. V. O. Quine, "On What There Is," *Review of Metaphysics* **2**, 21–38 (1948).

[4] E. Sober, *Ockham's Razors: A User's Manual* (Cambridge University Press, Cambridge, 2015).

[5] J. Norton, "The Hole Argument," *Stanford Encyclopedia of Philosophy* (2019).

[6] C. Barceló, S. Liberati, and M. Visser, "Analogue gravity," *Living Reviews in Relativity* **8**, 12 (2005).

[7] M. Visser, "Acoustic black holes: horizons, ergospheres and Hawking radiation," *Classical and Quantum Gravity* **15**, 1767–1791 (1998).

[8] A. D. Sakharov, "Vacuum quantum fluctuations in curved space and the theory of gravitation," *Soviet Physics Doklady* **12**, 1040–1041 (1968).

[9] T. Jacobson, "Thermodynamics of spacetime: The Einstein equation of state," *Physical Review Letters* **75**, 1260–1263 (1995).

[10] C. P. Burgess, "Quantum gravity in everyday life: General relativity as an effective field theory," *Living Reviews in Relativity* **7**, 5 (2004).

[11] J. F. Donoghue, "General relativity as an effective field theory: The leading quantum corrections," *Physical Review D* **50**, 3874–3888 (1994).

[12] T. Damour and G. Esposito-Farèse, "Tensor-multi-scalar theories of gravitation," *Classical and Quantum Gravity* **9**, 2093–2176 (1992).

[13] J. D. Bekenstein, "Relativistic gravitation theory for the modified Newtonian dynamics paradigm," *Physical Review D* **70**, 083509 (2004).

[14] S. S. McGaugh, F. Lelli, and J. M. Schombert, "Radial Acceleration Relation in Rotationally Supported Galaxies," *Physical Review Letters* **117**, 201101 (2016).

[15] L. Smolin, "The case for background independence," in *The Structural Foundations of Quantum Gravity*, eds. D. Rickles, S. French, and J. Saatsi (Oxford University Press, 2006).

[16] J. Earman and J. Norton, "What Price Spacetime Substantivalism? The Hole Story," *British Journal for the Philosophy of Science* **38**, 515–525 (1987).

[17] G. Unruh, "Experimental black-hole evaporation?," *Physical Review Letters* **46**, 1351–1353 (1981).

[18] S. Liberati, "Analogue gravity models of emergent gravity: lessons and pitfalls," *Journal of Physics: Conference Series* **880**, 012009 (2017).