Kernel Dominance in Gravity

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Subject: Formal classification of the graviton and gravitational observables under Kernel Law constraints.
Framework: History-Augmented Configuration Space $\mathcal{X}$ with Diffeomorphism-Invariant Observable Algebra $\mathcal{O}_{\mathrm{GR}}$.

Abstract

We apply the Kernel Law framework to General Relativity to classify the status of the graviton and gravitational observables. While perturbative gravity admits a particle interpretation in fixed-background Effective Field Theory, full diffeomorphism-invariant General Relativity admits no local, gauge-invariant operator corresponding to graviton number. We show that physically accessible observables are strictly relational, consisting of strain, asymptotic charges, and radiative flux, while the graviton arises as a coordinate-dependent excitation in the history space. This resolves the predictive success of perturbative gravity alongside the persistent difficulty of quantum gravity as a particle theory.

1. Executive Summary

Verdict: KERNEL-DOMINANT (CONFIRMED).

In perturbative General Relativity (GR) on a fixed background, one may decompose the metric as

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + h_{\mu\nu},$$

and quantize the transverse–traceless sector of $h_{\mu\nu}$, yielding graviton quanta in the Effective Field Theory (EFT) regime.

However, in full diffeomorphism-invariant GR, there is no canonical background–fluctuation split and no local, gauge-invariant operator corresponding to "graviton number" or "graviton density" in the spacetime bulk. The physically meaningful observable algebra is relational (e.g., geodesic deviation/strain, asymptotic charges, and radiative flux).

Under the Kernel Law, the perturbative graviton description primarily parameterizes redundancy (choice of chart) in the history space $\mathcal{X}$ rather than defining intrinsic elements of the physical quotient space

$$\mathcal{X}_{\text{phys}} = \mathcal{X}/\text{Diff}.$$

In this sense, gravity is strongly kernel-dominant: rich mathematical structure upstairs, thin observable shadow downstairs.

2. Part A — Formal Placement of the Graviton

2.1 Linearization and Gauge Structure

We define the history space $\mathcal{X}$ via metric perturbations $h_{\mu\nu}$ about a background metric $\bar{g}_{\mu\nu}$. Under infinitesimal diffeomorphisms

$$x^\mu \to x^\mu + \xi^\mu,$$

the perturbation transforms as

$$h_{\mu\nu} \to h_{\mu\nu} - \nabla_\mu \xi_\nu - \nabla_\nu \xi_\mu.$$

2.2 Mode Decomposition and Kernel Membership

At the linearized level, the perturbation decomposes as follows:

- **Gauge (Kernel) Modes:** Four degrees of freedom generated by ξ^μ, representing pure coordinate redundancy. These directions lie entirely within the Kernel.
- **Constraint Modes:** Four non-dynamical components fixed by the Einstein constraint equations and source terms.
- **Radiative Modes:** Two transverse–traceless (TT) degrees of freedom satisfying wave equations.

2.3 Operator Status and the Background Problem

The identification of the TT sector requires a background structure to define "transverse" and "traceless."

- **EFT Regime:** In asymptotically flat spacetimes or fixed-background EFT, this split is physically meaningful, and graviton states are well-defined asymptotic particle states.
- **Full GR:** In the bulk of a background-independent theory, the split is non-unique. There exists no local operator $\hat{N}_g(x)$ that is invariant under all diffeomorphisms. The "graviton" is therefore a coordinate-dependent excitation rather than an element of the diffeomorphism-invariant observable algebra.

3. Part B — Observable Algebra for Gravity

The physical observable algebra $\mathcal{O}_{\text{GR}}$ consists strictly of relational observables.

3.1 Observables Surviving the Quotient

- **Geodesic Deviation / Strain:** The relative acceleration and integrated distance change between freely falling test masses (e.g., LIGO strain $\delta L/L$).
- **Asymptotic Observables:** Bondi news (radiative flux), ADM mass, and the gravitational memory effect (permanent displacement).
- **Relational Invariants:** "Clock-and-rod" observables constructed physically from matter fields.

Note on Scalars: While curvature scalars such as R are diffeomorphism-invariant, they often vanish for vacuum gravitational waves (e.g., plane waves), making them poor operational proxies for radiation.

3.2 Information Eliminated by the Kernel

- **Metric Potential:** The local value of $h_{\mu\nu}$ is unobservable.
- **Local Gravitational Energy Density:** There is no diffeomorphism-invariant local tensor for gravitational energy density. The Equivalence Principle allows one to choose a local inertial frame in which connection coefficients vanish, removing any notion of local gravitational energy density, though tidal observables (curvature) remain measurable.

3.3 The Kernel Hook — Contrast with QED

- **QED:** The gauge potential A_μ is kernel-ish, but the field strength $F_{\mu\nu}$ and local energy density $(E^2 + B^2)$ are local, gauge-invariant observables. "Photon number" is robust.
- **Gravity:** Even the "field strength" analogue (Riemann curvature) is locally measurable via tidal forces, but energy and particle bookkeeping are not local and not gauge-invariant. The particle concept retreats into the history fiber more completely than in gauge theory.

4. Part C — Emergent Mathematics vs. Emergent Physics

Classification

The graviton is classified as an emergent *mathematical coordinate* in the Kernel: a useful parameterization of the history space $\mathcal{X}$ with no corresponding observable operator in the diffeomorphism-invariant algebra.

Explaining the Predictive Paradox

- **Why predictive?** Calculations work because the Kernel (history space $\mathcal{X}$) acts as a covering space for physical reality. Perturbation theory (Feynman diagrams) operates in $\mathcal{X}$, summing over gauge-redundant histories. The mathematics is valid within the fiber.

- **Why elusive?** Detection requires an operator $\hat{O} \in \mathcal{O}_{\text{GR}}$. Since "graviton number" is not diffeomorphism-invariant, no such detector can be constructed. We detect *classical gravitational waves*—collective shifts in the quotient geometry—but not the "particles" constituting them, because the discreteness is a feature of the gauge-fixed description, not of the observable algebra.

Final Verdict

Gravity is a theory of *Kernel Geometry*. The "particles" of gravity arise from projecting that geometry onto a fixed reference frame—a map that exists in our calculations, not in the observable universe. The graviton is therefore a powerful calculational artifact, not a fundamental observable constituent.