

# General Relativity and Regime Localization

## Regimes, Observation, and Curvature

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## Abstract

General Relativity is invariant under diffeomorphisms, yet the semantic consequences of this invariance are rarely made explicit. This paper provides a semantic completion of General Relativity by lifting its observational structure into a regime-based framework in which observation is treated as a non-intervening projection constrained by diffeomorphism invariance.. Observational outcomes are shown to form localized semantic regimes under curvature-relative equivalence, with no guarantee of global comparability. Only diffeomorphism-invariant quantities descend to regime-level meaning, while coordinate-dependent descriptions are discarded by the quotient structure. Familiar general relativistic phenomena—including gravitational time dilation, redshift, horizons, and singularities—are derived as corollaries of regime localization rather than as physical distortions. Geometry is shown to constrain the scope of semantic invariants without introducing new semantic primitives. The result is a mathematically disciplined framework in which curvature localizes meaning and observation projects without intervention.

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# 1 Motivation and Scope

General Relativity replaces global inertial structure with local geometric description. While its dynamical content is well understood, the semantic status of quantities reported in curved spacetime is often treated informally, via coordinate-based intuition.

This paper argues that semantic clarity must precede geometric interpretation. Before one can ask what spacetime curvature *does*, one must ask what can be *meant* in the presence of curvature.

The goal is not to alter Einstein’s equations, introduce new observables, or reinterpret ontology. The goal is to make explicit the regime structure already forced by diffeomorphism invariance and locality.

## 2 Core Definitions

Let  $(M, g)$  be a Lorentzian manifold representing spacetime.

### 2.1 Observational Contexts

**Definition 2.1** (Observational Context). An observational context is a triple  $(U, \chi, \mathcal{P})$  where:

- $U \subset M$  is an open subset,
- $\chi : U \rightarrow \mathbb{R}^4$  is a coordinate chart,
- $\mathcal{P}$  is a set of admissible observational procedures defined relative to  $\chi$ .

Observational contexts specify representation, not physical evolution.

### 2.2 Observational Outcomes

**Definition 2.2** (Observational Outcome). An observational outcome is the result of applying an admissible observational procedure within a fixed observational context.

Let  $\mathcal{O}_U$  denote the outcomes obtainable in  $U$ , and define the total observational space

$$\mathcal{O} = \bigsqcup_{U \subset M} \mathcal{O}_U.$$

### 2.3 Curvature-Relative Equivalence

**Definition 2.3** (Curvature-Relative Observational Equivalence). Two outcomes  $o \in \mathcal{O}_U$  and  $o' \in \mathcal{O}_{U'}$  are curvature-relatively equivalent if there exists a diffeomorphism  $\varphi : U \rightarrow U'$  preserving operational predictions such that  $o'$  is the pushforward of  $o$  under  $\varphi$ .

## 2.4 Curved Spacetime Semantic Regimes

**Definition 2.4** (Curved Spacetime Semantic Regime). A curved spacetime semantic regime is an equivalence class of observational outcomes under curvature-relative observational equivalence. Formally,

$$\mathcal{R}_{\text{GR}} = \mathcal{O} / \sim_{\text{curv}} .$$

**Definition 2.5** (Semantic Invariant). A semantic invariant is a function  $I : \mathcal{O} \rightarrow S$  such that  $I(o) = I(o')$  whenever  $o \sim_{\text{curv}} o'$ .

**Lemma 2.6** (Well-Definedness). *The relation  $\sim_{\text{curv}}$  is an equivalence relation, and semantic invariants descend uniquely to functions on  $\mathcal{R}_{\text{GR}}$ .*

*Proof.* Reflexivity, symmetry, and transitivity follow from the groupoid structure of local diffeomorphisms. Invariance ensures descent.  $\square$

## 3 General Relativity as a Regime System

**Lemma 3.1** (Local Regime Formation). *For any observational context  $(U, \chi, \mathcal{P})$ , the outcomes  $\mathcal{O}_U$  partition into local semantic regimes.*

**Proposition 3.2** (Failure of Global Regimes). *In a generically curved spacetime, local semantic regimes cannot be unified into a single global regime.*

*Proof.* Curvature obstructs the existence of global diffeomorphisms relating arbitrary domains, preventing global equivalence.  $\square$

**Theorem 3.3** (Curvature-Induced Regime Fragmentation). *Spacetime curvature fragments semantic regimes by restricting the domains over which observational equivalence may be defined.*

*Remark 3.4.* Meaning does not vanish in General Relativity; it localizes.

## 4 Semantic Regimes and Curvature

**Theorem 4.1** (Semantic Invariance in Curved Spacetime). *Only diffeomorphism-invariant properties descend to regime-level meaning.*

**Proposition 4.2** (Non-Semantic Status of Coordinates). *Coordinate-dependent quantities possess no observer-independent semantic meaning.*

*Remark 4.3.* Geometry does not distort meaning; it bounds its domain.

## 5 Observation Without Intervention

**Definition 5.1** (Observation as Semantic Projection). Observation is a projection

$$\pi_U : \mathcal{O}_U \rightarrow \mathcal{R}_U$$

preserving semantic invariants without executing physical change.

**Theorem 5.2** (Non-Intervention Principle). *Observation in curved spacetime does not induce physical state change.*

**Proposition 5.3** (Horizons as Observational Boundaries). *Horizons delimit semantic projection without implying physical discontinuity.*

*Remark 5.4.* Observation projects. Curvature decides where projection stops.

## 6 Semantic Interpretation of GR Phenomena

**Corollary 6.1.** *Gravitational time dilation is a regime-relative semantic effect.*

**Corollary 6.2.** *Redshift reflects regime-relative signal description, not energy loss.*

**Corollary 6.3.** *Singularities correspond to breakdown of semantic continuation.*

*Remark 6.4.* Curvature localizes meaning before it alters dynamics.

## 7 Invariance, Geometry, and Meaning

**Definition 7.1** (Semantic Invariance). A quantity is semantically invariant if it descends to a function on  $\mathcal{R}_{\text{GR}}$ .

**Theorem 7.2.** *Geometry constrains the extensibility of semantic invariants without generating new ones.*

## 8 Epistemic Scope and Non-Goals

This theory introduces no new dynamics, observables, or ontological commitments. It clarifies structure already present.

## 9 Conclusion

General Relativity reorganizes meaning before it modifies physics. Curvature fragments regimes, observation projects locally, and global semantic comparability is generically unavailable. Geometry

bounds meaning; it does not create it.

## A Appendix F: References

### References

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