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# Laws as Constraint Residues: Toward a Structural Ontology of Law

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**Abstract**

This paper proposes a structural account of scientific laws as stabilized residues of constraint regimes, rather than as metaphysical primitives or regularities. Drawing on recent developments in the philosophy of science and structural ontology, we argue that lawhood arises from the persistence of invariant patterns across admissible variations within a regime of constraint. Our framework reconceives laws as functional invariants extracted from the internal architecture of scientific models, formalized via projection operators and local neighborhoods in constraint space. This structural residue approach captures the operational role of laws in guiding prediction, explanation, and theoretical unification, while remaining neutral on ontological commitments to universals or modal realism. We compare our proposal with alternative accounts of lawhood, including counterfactual stability (Lange) and interventionist invariance (Woodward), and conclude by outlining the implications of our framework for the natural and social sciences.

Keywords: scientific laws; structural realism; constraint regimes; invariance; projectibility; explanation

# 1 Introduction: The Ontological Question of Law in a Post-Representational Context

The status of scientific laws remains one of the central ontological problems in the philosophy of science. While scientific practice continues to rely on formal expressions labeled as "laws," the ontological grounding of these entities has become increasingly opaque. Traditional metaphysical accounts are no longer adequate to capture the structural complexity and contextual contingency of contemporary scientific theory. In particular, the classical opposition between nomological realism and Humean supervenience has reached a point of conceptual saturation. According to the realist tradition, scientific laws are ontologically robust entities that govern the behavior of physical systems. On this view, laws are necessary features of the world, responsible for the modal structure of reality and irreducible to empirical generalizations. D.M. Armstrong's position exemplifies this approach: laws are relations between universals, metaphysically necessary and explanatory in virtue of their governing power (Armstrong, 1983). Tim Maudlin has similarly argued that laws must be considered primitive components of the ontology in order to sustain their explanatory and modal roles (Maudlin, 2007).

By contrast, the Humean tradition, most prominently articulated by David Lewis, rejects the ontological autonomy of laws. Instead, laws are construed as theorems in the simplest and most informative systematization of the mosaic of local matters of fact, the so-called Best System Account (BSA) (Lewis, 1994). On this view, laws do not govern the world but summarize it; they reflect regularities rather than enforce them. Their status is derivative, epistemically useful but metaphysically deflationary. Both paradigms, however, face increasing difficulties in accounting for the functional role of laws within the fragmented and constraint-driven architecture of modern science. Nomological realism overburdens laws with explanatory power while ignoring their empirical plasticity and domain sensitivity. The Humean model, in turn, collapses the modal structure of lawfulness into descriptive regularity, failing to explain the operational stability and projectibility of scientific laws across theoretical domains. In light of these limitations, this article proposes a third path: to reconceive scientific laws not as governing entities or optimal summaries, but as *constraint residues*, structurally stabilized outputs of regimes of constraint operative within scientific practice. This perspective aligns with recent developments in structural realism and epistemology of modeling, which emphasize the architectural role of constraints in the generation, validation, and projection of scientific knowledge (Frigg and Nguyen, 2020; Votsis, 2011; Ladyman and Ross, 2007).

The guiding thesis is that scientific laws are not primitive axioms of reality, nor statistical compressions of data, but stabilized expressions of structural compatibility within constraint regimes. They emerge not from metaphysical postulation or inductive abstraction, but from the convergence of structural, empirical, and projective constraints that delimit what can be meaningfully stabilized, transferred, and actualized across scientific contexts. This reframing demands a new ontology of law: one that treats lawfulness as the residue of constraint stabilization, not as an independent ontological category. In what follows, we formalize this account and demonstrate its relevance for understanding the ontological status, explanatory function, and epistemic validity of scientific laws in a non-representational, structurally stratified framework.

## From Primitive Entities to Constraint Residues

Despite their ontological opposition, both nomological realism and Humean reductionism share a common presupposition: that scientific laws are either *primitive* constituents of reality or *compressive* summaries of empirical patterns. In both frameworks, laws are treated as self-standing entities, either as metaphysically irreducible (realism) or as systemically derived from a totality of facts (Humeanism). Neither approach, however, accounts for the structural genesis of laws within scientific practice itself. This shared omission becomes particularly problematic in the context of contemporary science, where theoretical frameworks are increasingly shaped by domain-specific modeling constraints, inferential architectures, and projective heuristics. Scientific laws do not emerge in a vacuum; they are stabilized within, and constrained by, structured regimes of experimental, formal, and semantic conditions. The absence of this structural anchoring in traditional accounts leaves unexplained how laws acquire their operative stability, why they exhibit selective domain applicability, and what underwrites their epistemic robustness.

Against this backdrop, we propose a reconceptualization of scientific lawfulness: *laws are neither primitive nor epiphenomenal, but residual.* That is, they are stabilized outputs, *constraint residues*, emerging from the convergence of operative regimes that delimit the admissible space of empirical and theoretical articulation. A constraint residue, in this sense, is not a metaphysical entity but a structurally persistent expression of compatibility within a constraint architecture. This hypothesis entails a shift in ontological perspective. Rather than asking what laws *are* in isolation, we ask how laws *persist* as structural residues of stabilized interactions among theoretical, empirical, and projective constraints. Such a framework not only dissolves the dichotomy between realism and regularism, but also integrates the emergence, applicability, and functional role of laws into a unified structural ontology. In this view, the law is not what governs the system, but what survives the stabilization of constraint dynamics.

# 2 From Governing Laws to Structural Residues: A Critical Review

## 2.1 Nomological Realism and Its Ontological Burden

Nomological realism maintains that scientific laws are objective features of the world that do more than summarize patterns: they underpin modal structure and sustain explanation. This realist family is, however, heterogeneous. Some versions construe laws as relations among universals (e.g. Armstrong), whereas others defend a primitivist or non-reductive conception of lawhood as ontologically basic (e.g. Maudlin). Our target in what follows is not "realism" as such, but the governing-entity picture insofar as it leaves under-articulated the bridge between lawhood and the operational conditions under which laws are identified, stabilized, and applied in scientific practice.

A first pressure point concerns the epistemology of governing. Realists often motivate laws by appeal to their explanatory role, and it is natural to invoke inference to the best explanation in this context. The difficulty is not that IBE is illegitimate, but that, without an account of the regime-conditions that make a principle admissible and projectible, the realist dialectic risks a form of explanatory circularity: the evidential route to positing a law typically proceeds via regularities and stable model-based patterns, yet these are then redescribed as holding *because* of the law. What is missing is not explanation per se, but an operationally explicit account of how scientific practice fixes the relevant predicates of stability, the admissible transformations under which a principle remains invariant, and the conditions under which it can be exported across modelling contexts. In van Fraassen's terms, the worry is that absent such structure the appeal to laws threatens to become explanatorily idle with respect to the very practices that are supposed to support it (van Fraassen, 1989).

A second pressure point concerns *selective applicability* and *domain sensitivity.* Even granting, for the sake of argument, that there may be universally governing fundamental laws, a large class of scientifically central lawlike generalizations are effective, derived, or regime-bound: their validity depends on explicit constraints, idealizations, and boundary conditions. Thermodynamic generalizations are a case in point. They are typically obtained via statistical-mechanical derivations together with coarse-graining and boundary constraints (e.g. low-entropy boundary conditions), so their stability and scope are mediated by a structured constraint set rather than by an unrestricted, metaphysically global governing role. The dialectical point is therefore not that realism about fundamental laws is incoherent, but that an appeal to a privileged fundamental level does not by itself explain how regime-level lawfulness is fixed, stabilized, and exported across modelling contexts. Without an explicit representation of the constraint architectures that underwrite derivation and applicability, the governing-entity picture risks either downgrading such principles as non-laws (at odds with scientific practice) or misdescribing them as globally governing.

Accordingly, we remain neutral on whether there exist universally governing fundamental laws; our claim is that scientific lawhood, as operationally deployed, is stratified and regime-relative, and thus requires an account of constraint-mediated stabilization rather than reliance on fundamentality alone.

Finally, even when lawhood is taken to be ontologically robust (whether via universals or primitivism), the realist framework often leaves under-specified how lawhood connects to the model-mediated and constraint-driven architecture of contemporary science. The issue is not that realist laws are "epistemically detached" in any simple sense: a primitivist may, for instance, define laws functionally as whatever grounds the relevant regularities. The issue is rather that, without a structural mechanism for admissibility, stabilization, and projectible transfer, the governing-role of laws remains too coarse-grained to track the stratified, regime-relative character of scientific lawhood. These limitations motivate an alternative account in which lawhood is not treated as a primitive metaphysical posit, but as a structurally emergent output of constraint architectures, developed in subsequent sections.

## 2.2 Humean Supervenience and the Compression Thesis

In contrast to realist positions, Humean approaches aim to avoid ontological inflation by treating laws as derivative of the mosaic of local matters of particular fact. The most influential formulation is David Lewis's Best System Account (BSA), on which laws are theorems of the deductive system that best balances simplicity and strength in describing the total distribution of local qualities (Lewis, 1973, 1994). On this view, laws do not govern or necessitate; they summarize. This yields the familiar *compression thesis*: lawhood is a function of optimal systematization, not an additional worldly ingredient.

The standard objection is that such compression seems to thin out modal force. However, it would be a mistake to claim, without qualification, that Humean accounts *cannot* accommodate robustness, counterfactual support, or projectibility: the Humean literature contains sophisticated replies, for instance by enriching best-system virtues with constraints of naturalness, fit, or context-sensitivity. The more precise concern is methodological and structural. The BSA explains lawhood by global optimization over the total mosaic, whereas much scientific practice fixes lawlike stability through *layered constraint architectures* that are local, model-mediated, and regime-relative. In domains such as quantum theory, climate modelling, or systems biology, the operative sources of stability are not merely regularities, but admissibility constraints, symmetry structures, computational frameworks, and projective norms that determine what counts as a stable generalization within a domain of use (Massimi, 2022; Leonelli, 2016). A purely global best-system perspective therefore risks underdescribing (i) how these local constraint regimes are constructed, and (ii) why stability under domain-relevant perturbations supports the specific forms of projection and transfer that scientific laws routinely enable.

Moreover, the BSA does not exhaust Humeanism, and even within BSA-style approaches a natural reply is a two-level picture: the best system yields fundamental laws, while non-fundamental or special-science laws are derived. Grant this reply. A further question then becomes pressing: what is the derivational relation supposed to preserve, if scientific lawhood essentially involves admissibility under perturbations, robustness across modelling choices, and projective transfer across representational contexts? Without an account of how constraint architectures and their tolerances enter into the derivation, the two-level strategy risks reintroducing, at the level of scientific practice, exactly what BSA abstracts away from: the structured nexus of regime-constraints that makes lawlike stability operationally intelligible. Recent "human-centric" or practice-sensitive refinements of best-system approaches reinforce the point by making explicit the role of epistemic aims and modelling choices in system-selection; yet this very move strengthens the case for a framework that represents constraint-mediated stabilization directly rather than treating it as a byproduct of global compression.

A useful stress-test for this diagnosis is provided by hybrid accounts that combine a non-Humean ontological base with a best-system theory of laws. Demarest's Potency-Best System view, for instance, retains an anti-Humean metaphysics of fundamental potencies while treating laws themselves as the axioms of the simplest, most informative true systematization; in this sense, laws are "powerless" and do not govern, while modal work is carried by the potency base (Demarest, 2017). This hybrid strategy avoids a purely categorical mosaic, yet preserves the best-system explanatory template. Our proposal is compatible with the negative lesson that lawhood need not involve primitive external governance, but it departs from the best-system approach (even in hybrid form) on what fixes lawlike stability in scientific practice. On the constraint-residue framework, lawhood is not primarily a matter of globally systematizing a distribution (whether of categorical properties or potencies), but of identifying invariants under admissible transformations and perturbations within a regime, where admissibility is fixed by a layered architecture of structural, empirical, and projective constraints.

In sum, Humean compression offers an elegant deflationary account of lawhood, but it tends to treat the constraint-driven architecture of science as explanatorily downstream of an optimal summary. This leaves open how localized constraint regimes yield the kind of stability and projectible applicability that scientific laws exhibit in practice. The constraint-residue framework developed below is designed to address precisely this gap: it relocates lawhood from global description or metaphysical governance to regime-stabilization under explicitly articulated structural, empirical, and projective constraints.

## 2.3 Toward a Constraint-Based Alternative

The critical analyses above reveal a shared limitation in both nomological realism and Humean supervenience: neither yields an operationally grounded, structurally oriented account of scientific law. Some realist views risk treating lawhood as metaphysically primitive in a way that obscures the epistemic route by which laws are identified and applied in practice. Some Humean views, by contrast, risk flattening the layered structure of modelling and experimentation into an optimising summary of global regularities, thereby underdescribing the role of constraint architectures in theory construction and validation.

What is missing in both cases is a framework in which laws are neither metaphysical primitives nor mere descriptive condensations, but systematically tied to the regimes through which scientific practice stabilises representational and inferential possibilities. In particular, neither tradition foregrounds the iterative interplay among structural symmetries, empirically fixed constraints, and projective requirements that jointly delimit what counts as an admissible formulation, a stable application, and a reliable transfer of a candidate law across contexts.

**Alternative Approaches.** Several contemporary proposals aim to reconceptualize laws without committing to either primitivism or regularism. For instance, Lange (Lange, 2000) characterizes laws as members of maximally stable sets of truths under counterfactual support, while Woodward (Woodward, 2003) defines them in terms of their role in invariant causal explanations. Although our account differs in both formalism and ontology, it shares with these views the commitment to the functional role of laws in structuring scientific practice. Unlike Lange's counterfactual stability or Woodward's interventionist invariance, our approach grounds lawhood in the persistence of constraint-structure across admissible transformations.

A closely related family of views has recently been developed under the heading of *constraint accounts* of laws, motivated by the claim that the Newtonian time-evolution paradigm is too narrow for contemporary physics, where fundamental principles often take the form of global, atemporal, and "all-at-once" constraints on physical possibility (e.g. Adlam, 2022; see also Meacham, 2023). These approaches typically treat laws as primitive modal constraints, thereby gaining flexibility across non-dynamical cases, but they face a standing pressure point: absent further structure, "constraining" can appear under-specified, inviting either a covert causal-governance reading or a notion so weak as to be compatible with Humean descriptivism (Meacham, 2025, 2023).

A salient representative of the primitivist wing is Chen and Goldstein's *Minimal Primitivism* (MinP), which aims to retain a governing conception of laws while remaining maximally permissive about the possible *forms* of fundamental laws. On MinP, laws are *primitive facts* that govern by *constraining the space of nomological possibilities*, without presupposing a fundamental direction of time and without reducing laws to universals, powers, or dispositions. The constraining relation itself is taken to be metaphysically basic, and the principal payoff is a unified governing framework hospitable to non-dynamical and global principles. (Chen and Goldstein, 2022)

The present proposal shares the same naturalistic motivation, but departs both ontologically and methodologically. It does not posit constrainthood as primitive, nor does it ground lawhood in a single fundamental nomic relation (as in the Nomic Likelihood Account; Meacham, 2023). Instead, it relocates the notion of constraint from a primitive governing relation to an *operationally articulated regime structure*. Lawhood is identified with *constraint residues*, namely stable invariants extracted from the iterative co-stabilisation of structural symmetries, empirically fixed constraints, and projective requirements within scientific practice. Admissibility is fixed by this layered nexus (structural, empirical, and projective), and modal force is internal to regime-stability and robustness conditions rather than an external governing role. On this view, "constraining" is rendered operationally substantial by explicit stability and projectibility criteria.

We therefore propose to reconceive scientific laws as *constraint residues*: stabilized outputs of empirically operative regimes of constraint. A constraint regime, as developed in previous work (Frigg and Nguyen, 2020), is a structured configuration of limitations, invariances, and admissibility conditions that shapes the inferential and projective space of scientific activity. Laws, in this framework, are not axiomatic, but derivative: they are the residual invariants that persist *given* the stabilisation of such a regime. They are neither universal nor merely contingent in the usual sense, but structurally anchored and regime-relative.

This account captures both the *structural anchoring* and the *functional role* of laws while avoiding two familiar extremes. It neither invokes metaphysical necessity via primitive governance nor reduces lawhood to system-wide regularity. Rather, it treats law-statements as byproducts of constraint-mediated coherence: they express residues of compatibility across empirical, formal, and projective dimensions of a regime. In this respect, the notion of law shifts from ontological substance to operational stability, and from external governance to architectural convergence. The remainder of this article develops the formal structure and ontological implications of this reconceptualization.

# 3 Formal Definition: Laws as Constraint Residues

## 3.1 Regimes of Constraint and Their Residual Output

To articulate an ontologically grounded and formally coherent notion of scientific law, we introduce the concept of a *constraint regime*. Rather than postulating laws as independent primitives or statistical summaries, we define them as structural residues stabilized through the convergence of constraints operative within scientific domains. The first step is to formally characterize the architecture of such regimes.

**Definition 1.** *A* constraint regime *is a triplet*

$$\mathcal{C} = (C_s, C_e, C_p)$$

*where:*

- $C_s$ *is the set of* ***structural constraints****, such as symmetries, topological invariants, conservation principles, or group-theoretic relations. These define the formal architecture within which a theory is constructed.*
- $C_e$ *is the set of* ***empirical constraints****, including reproducible measurements, experimental invariants, and operational conditions of access. These reflect the stability and reliability of empirical input under specific configurations.*
- $C_p$ *is the set of* ***projective constraints****, encompassing requirements of intelligibility, completeness, or theoretical consistency. These constraints are often epistemic or semantic in nature, specifying which forms of representation are admissible or desirable within a scientific practice.*

Each component of the triplet $\mathcal{C}$ plays a distinct but interdependent role in delimiting the space of admissible models and in stabilizing the inferential pathways through which scientific results are produced. Structural constraints ($C_s$) provide a formal skeleton; empirical constraints ($C_e$) anchor the theory to measurable and repeatable content; projective constraints ($C_p$) guide the extrapolation and generalization of theoretical constructs across domains. The intersection and co-stabilization of these constraints generate a space of admissible trajectories for theory formation. Within this space, certain structural features persist across variations, approximations, or model refinements. These persistent features, those that survive the convergence of $C_s$, $C_e$, and $C_p$, constitute what we term a *constraint residue*.

**Definition 2.** *Given a constraint regime $\mathcal{C} = (C_s, C_e, C_p)$, a* constraint residue *$\mathcal{R}$ is a stabilized structural invariant that persists under the joint application of the regime's components. That is,*

$$\mathcal{R} := \mathrm{Res}(\mathcal{C}) = \lim_{\epsilon \to 0} \Pi(\mathcal{C}_\epsilon)$$

*where $\mathcal{C}_\epsilon$ denotes a family of perturbations of the regime within admissible tolerances, and $\Pi$ is a projection onto the space of stable invariants.*

This definition formalizes the intuition that scientific laws are not introduced ab initio, but rather emerge as invariant residues of structurally constrained stabilization processes. A law, in this sense, is a *residual operator* within a constraint manifold: it is what remains fixed across admissible variations, and what ensures the compatibility of structural, empirical, and projective demands within a domain of intelligibility. While this definition captures the idea of persistence under perturbation, it remains formally underdetermined unless the nature of the residue is further specified. We propose to interpret $\mathrm{Res}(\mathcal{C})$ not merely as a limit in a metric sense, but as a structural invariant in the topological or cohomological space associated with the constraint architecture.

Let $\mathcal{C}$ define a sheaf of admissible constraints over a base space of experimental or structural configurations. Then $\mathrm{Res}(\mathcal{C})$ may be characterized as a *weak topological invariant*, such as a class in the first Čech cohomology group $H^1(\mathcal{C}, \mathcal{F})$, where $\mathcal{F}$ encodes projective compatibilities. This captures the idea that the law is what remains globally coherent across locally compatible constraint patches. In this formalization, a law is not a syntactic expression but a *cocycle class*, an equivalence class of transition functions between constraint charts that preserve empirical coherence. The lawhood of a relation thus reflects its position as a *nontrivial global section* of a regime-dependent sheaf, rather than a direct consequence of local features.

Such a formulation links naturally with contemporary applications of sheaf theory in the modeling of context-dependence and measurement structure in quantum theory (Abramsky and Brandenburger, 2011), and with the interpretation of physical laws as constraints on global consistency rather than pointwise truth.

### 3.2 Law as a Projectible Residue

Having defined a constraint regime as a structured triplet $\mathcal{C} = (C_s, C_e, C_p)$, we now formalize the notion of a scientific law as a *projectible residue* of such a regime. The key idea is that what we call a "law" in scientific discourse is not a primitive or global rule but a stabilized projection: a structural invariant that persists across the admissible variations of the constraint system.

**Definition 3.** *A* scientific law *$\mathcal{L}$ is defined as the projectible residue of a constraint regime $\mathcal{C}$, formally given by:*

$$\mathcal{L} := \mathrm{Res}(\mathcal{C}) = \lim_{\epsilon \to 0} \Pi(\mathcal{C}_\epsilon)$$

*where $\mathcal{C}_\epsilon$ denotes an $\epsilon$-perturbation family of the regime $\mathcal{C}$ within the bounds of admissibility, and $\Pi$ is a projection operator selecting structural invariants under constraint-induced transformations.*

This formulation captures the intuition that laws are those features of theoretical structure which remain fixed under empirically and conceptually tolerable deformations. In this sense, a law is not an assertion about the totality of nature but a *localized structural persistence*, what survives after the convergence of symmetries, empirical adequacy, and theoretical coherence. The notion of *projectibility* employed here echoes the discussion in Goodman's classic problem of induction (Goodman, 1955), but reframed structurally: a predicate or expression is projectible not by linguistic fiat or past success, but by its stability under constraint-convergence. The projection operator $\Pi$ thus represents a kind of structural filtration: it selects those invariants that are *coherent*, *empirically reliable*, and *semantically transferable* within a domain of theory use.

$$\mathcal{L} := \mathrm{Res}(\mathcal{C}) := \bigcap_{\varepsilon \in \mathcal{N}(0)} \Pi(\mathcal{C}_\varepsilon) \quad \text{where } \mathcal{N}(0) \text{ is a filter of admissible perturbations.}$$

This formalization replaces the metric limit with a topological notion of intersection over a neighborhood system. Here, $\mathcal{N}(0)$ denotes a directed set of constraint perturbations converging to $\mathcal{C}$, typically understood as a filter base of perturbations admissible under the regime's operational tolerance. The law $\mathcal{L}$ is thus the structure that remains invariant under all such perturbations, a *residual invariant* of the constraint architecture.

**Clarification.** The projection operator $\Pi$ should not be understood as a geometric or linear projection in the usual sense, but as a structural filter that selects the invariants persisting under constraint variation. More precisely, $\Pi(C_\varepsilon)$ designates the set of constraint features that remain stable under a deformation $\varepsilon$ of the regime $C$, where $\varepsilon$ indexes admissible perturbations of empirical, structural, or projective conditions. The intersection over $\mathcal{N}(0)$ identifies features invariant across all such tolerances. Thus, $\mathrm{Res}(C)$ is not merely a syntactic limit but a stabilized structural residue defined by convergence under admissible variation. The neighbourhood $N(0)$ is not an arbitrary choice of "nearby" cases, nor a mere relabelling of Goodman-style projectibility. It is fixed, and continuously revised, by the regime's constraint architecture. Concretely, $N(0)$ is determined by: (i) metrological tolerances and calibration constraints that delimit indistinguishable variations at the relevant resolution; (ii) controlled intervention ranges that define which manipulations are physically and experimentally implementable; (iii) domain-natural reparameterisations and representation changes under which quantities retain a stable identification and inferential role; and (iv) robustness across modelling frameworks, where the same dependence survives across non-equivalent idealisations and model families (in the sense captured by robustness analyses in the philosophy of modelling). On this basis, admissibility is practice-mediated but world-anchored: the world constrains which perturbations can be stably tracked and which re-descriptions preserve representational content. This does not dissolve Goodman's problem by fiat. It yields a structural condition on projectibility: predicates and generalisations are projectible *within a regime* only if they remain stable under admissible perturbations and transformations as fixed by $N(0)$. "Grue-like" predicates fail not because they are metaphysically illegitimate, but because they do not sustain stable identification and invariance across the admissible re-descriptions and intervention-ranges that constitute the regime. If projected stability fails, the appropriate response is not to postulate an external governing necessity, but to revise the regime, including the admissibility structure (hence $N(0)$), in light of breakdowns of robustness and transport.

**Why this stability is not merely criterial.** The foregoing condition on projectibility should not be read as a merely methodological test superimposed on an otherwise unconstrained domain. The admissible neighbourhood $\mathcal{N}(0)$ is itself fixed by a regime's layered architecture of constraint, and that architecture is answerable to the way the target domain sustains or fails to sustain stable dependence under intervention, re-description, and model-variation. In this sense, stability under admissible perturbation is evidentially operational, but ontologically indicative: it tracks whether the dependence picked out by a candidate law is anchored in the structure of the domain rather than in an accident of representation, calibration, or local fit.

What the framework explains, therefore, is not merely why some predicates are retained and others discarded, but why certain generalizations support transport across contexts at all. A generalization is projectible in regime $\mathcal{C}$ only if the dependence it expresses is preserved across those variations that leave the regime's structural, empirical, and projective identity intact. Where such preservation obtains, we are not simply projecting past regularity forward; we are tracking a dependence that remains invariant across admissible actualizations of the same constraint architecture. Where it fails, the breakdown is not merely epistemic. It reveals that the putative law was not keyed to a stable structure of the domain under the admissible transformations that define its field of application.

This is why the present view does more than redescribe Goodman-style success conditions. It offers a world-anchored account of projectibility without invoking primitive governing necessities: lawhood attaches to those residual invariants whose stability is explained by the persistence of the relevant constraint architecture across admissible actualizations, not merely by their past usefulness or descriptive economy.

This approach also connects to the notion of theoretical robustness developed in the philosophy of modeling, where features that persist across different models and approximations are deemed explanatorily significant (Wimsatt, 1981; Weisberg, 2013). Laws, on this view, are precisely those robust elements that endure across structurally constrained variations of models, experiments, and inferential scaffolds. It follows that scientific laws, understood as projectible residues, are inherently regime-relative. They do not express absolute truths, but rather stabilize what can be rendered intelligible, reliable, and predictive within a given constraint manifold. Their scientific role lies not in governing reality, but in ensuring the reproducibility and coherence of constrained actualization processes across empirical and theoretical domains.

In this structural framework, lawhood is not a metaphysical predicate but a modal-functional status:

it names the outcome of a stabilization process across constraints. This marks a significant departure from both realist and Humean accounts, replacing ontological primacy and descriptive compactness with structural projectibility as the condition for scientific generalization.

### 3.3 Law and Structured Actualization

Building upon the structural definition of scientific laws as projectible residues, we now turn to their dynamic role in domain-specific instantiation. That is, we shift from their structural stabilization to their operational commutativity with actualization processes. To this end, we introduce the notion of *structured actualization*. Let $\mathcal{C}$ be a constraint regime, and let $\mathrm{Act}_D$ denote the actualization operator associated with a specific domain $D \subset M$, where $M$ is the total constraint manifold. The operator $\mathrm{Act}_D$ formalizes the selection, realization, or enactment of particular configurations of $\mathcal{C}$ within empirically or theoretically localized contexts.

Formally, we define the law–actualization compatibility condition as:

$$\mathcal{L} \circ \mathrm{Act}_D = \mathrm{Act}_D \circ \mathcal{L}$$

where $\mathcal{L}$ is the residual operator associated with $\mathcal{C}$, and both operators act on the space of admissible configurations. This expresses that the law commutes with the actualization process: applying the law before or after realizing the regime within domain $D$ leads to equivalent outcomes. Equivalently, this can be expressed as a vanishing commutator:

$$[\mathrm{Act}_D, \mathcal{L}] = 0 \quad \text{in } \mathrm{End}(\mathcal{A}),$$

indicating that the law preserves the structural coherence of actualizations in the space $\mathcal{A}$ of admissible configurations. This algebraic formulation mirrors conditions of invariance found in operator algebras and dynamical systems, where conserved quantities commute with the generators of evolution.

The philosophical significance of this condition is that a scientific law is not globally universal, but *locally compatible* with the structure of actualization. On the constraint-residue view, a law holds not in virtue of an external governing relation, but in virtue of being an invariant of a stabilised constraint regime. Its modal import is internal to the regime's admissibility structure: it constrains what counts as a legitimate variation, intervention, or re-description for purposes of explanation and projection, and it remains applicable only so long as those admissibility conditions continue to be satisfied. This perspective aligns with modal and categorical frameworks in which commutativity encodes preservation of structure under morphisms (Awodey, 2010; Landry, 2013). In categorical terms, constraint regimes define objects, actualization operators define morphisms, and laws are endomorphisms $\mathcal{L} \in \mathrm{End}(\mathcal{A})$ such that the following diagram commutes:

$$\begin{array}{ccc} \mathcal{A} & \xrightarrow{\mathcal{L}} & \mathcal{A} \\ {\scriptstyle \mathrm{Act}_D}\downarrow & & \downarrow{\scriptstyle \mathrm{Act}_D} \\ \mathcal{A} & \xrightarrow[\mathcal{L}]{} & \mathcal{A} \end{array}$$

The law is thus not an ontological decree, but a dynamically validated morphism in the category of constrained actualizations. Its applicability is conditional upon structural compatibility: it holds whenever it stabilizes admissible transformations without disrupting the constraint-induced coherence of the domain. This formulation supports an understanding of scientific law not as a syntactic or metaphysical absolute, but as a structured invariant that preserves operational admissibility across local instantiations of regimes.

If Section 3.2 defined what a scientific law is, structurally, this section has shown how it functions, dynamically, within the operational architecture of actualization. The lawhood of $\mathcal{L}$ lies in this commutative compatibility, not in universal imposition.

### 3.4 Status of Constraints and World-Anchoring

A central commitment of the constraint-residue framework is that constraints are not free choices layered on top of an otherwise unconstrained mosaic. A *constraint* is, in the first instance, a condition of *admissibility*: it specifies which models, representations, parameterisations, and inferential moves count as permissible within a given scientific regime. In this sense, constraints are neither mere descriptions of what happens, nor sui generis governing entities. They are normative in form (they regulate admissibility), yet world-sensitive in content (they are answerable to robust empirical and structural features that scientific practice tracks and exploits).

We model a regime of constraint as $C = (C_s, C_e, C_p)$. Each component plays a distinct role and carries a distinct ontological and epistemic profile.

**Structural constraints ($C_s$).** $C_s$ collects constraints induced by the structural organisation of the theoretical framework: symmetry principles, state-space structure, kinematic restrictions, covariance requirements, gauge redundancies, and the admissible transformation families that preserve the relevant representational content. Ontologically, $C_s$ is not a mere bookkeeping device: it encodes invariance structure that is stable across a wide range of modelling choices and that functions as a constraint on what can count as an admissible representation of the target system. Epistemically, $C_s$ is accessed through theoretical reconstruction and unification, but it is constrained by the success and stability of the representational practices it licenses.

**Empirical constraints ($C_e$).** $C_e$ captures the constraints imposed by experimental protocols, instrumental tolerances, calibration procedures, and robust regularities under controlled interventions. The key point is that $C_e$ is not "in the head": although it is articulated through practice, it is indexed to repeatable stability relations in the world, manifested in the reproducibility of measurements, in the persistence of response profiles under perturbations, and in cross-context convergence of independently implemented procedures. In other words, $C_e$ is practice-mediated but world-anchored: it constrains modelling because the world constrains successful experimental performance.

**Projective constraints ($C_p$).** $C_p$ concerns the conditions under which results may be exported, generalized, and transported across contexts: semantic transport across representational frameworks, controlled extrapolation beyond the calibration domain, and stability under admissible idealizations. $C_p$ is normative, but not arbitrary. It is fixed by coherence constraints internal to scientific practice (e.g. consistency of identification of quantities across models, preservation of inferential roles under reparameterisation, and projective stability under admissible perturbations), and it is continually tested by failure modes of projection (breakdowns that force regime refinement). Thus $C_p$ functions as a disciplined bridge between within-regime success and cross-context applicability.

This tripartite articulation yields a precise anchoring thesis: constraints are *world-involving* without being metaphysically primitive governors. $C_e$ anchors constraint architectures to stable experimental performance; $C_s$ constrains admissible representation by invariance structure; $C_p$ constrains projection by coherence and stability requirements that are themselves answerable to empirical breakdown and regime revision. Constraint architectures are therefore neither mere conventions nor purely descriptive summaries: they are structured admissibility conditions under which scientific practice can stably identify, apply, and extend lawlike generalisations. This also blocks two potential collapses.

**No collapse into Humean descriptivism.** On a purely Humean reading, constraints would reduce to (or supervene on) an optimal summary of the total distribution of local facts. By contrast, the present framework treats admissibility as fixed by layered constraints that are not exhausted by actual regularities. First, $C_s$ fixes transformation- and representation-classes relative to which invariants are defined; these classes are not read off from the mosaic but articulated through symmetry and state-space structure. Second, $C_p$ encodes projective commitments: it constrains which counterfactual variations and model-extensions count as legitimate tests of stability. Thus lawhood depends on stability under *admissible* perturbations and transformations, not merely on compression of actual occurrences. The modal profile of laws, on this view, is anchored in regime-stability conditions rather than derived from a global descriptive optimum.

**No collapse into primitive-governance nomological realism.** Conversely, on a governing-entity picture, laws would be primitive facts that impose constraints from "outside" scientific practice. The constraint-residue framework rejects this direction of explanation. Constraining is not a metaphysically basic relation added to the ontology; it is an operationally articulated nexus of admissibility conditions whose content is fixed by the co-stabilization of $C_s$, $C_e$, and $C_p$. Laws are therefore not antecedent limiters of possibility; they are *residues* extracted as invariants once a regime has stabilized. This makes lawhood derivative without making it conventional: derivative because it depends on regime stabilization, non-conventional because stabilization is constrained by world-anchored empirical performance and by robust invariance structure.

In sum, $C = (C_s, C_e, C_p)$ supports a restrained but substantive ontology: scientific lawhood is grounded in stability of invariants under admissible transformations and perturbations fixed by a regime, where admissibility is neither arbitrary nor metaphysically primitive. This is the sense in which laws are constraint residues: stable outputs of a world-anchored, practice-articulated constraint architecture.

# 4 Structural Ontology and the Stratification of Law

## 4.1 Law as a Stabilized Section

To consolidate the structural ontology of law proposed thus far, we now reinterpret scientific laws in the language of fiber bundle theory. This mathematical framework offers a natural setting for expressing the stratified and localized nature of scientific lawhood as stabilized across constrained domains. On this view, laws are not global axioms but *sections* stabilized over operational bases of constraint.

Let $\pi : E \to B$ denote a smooth fiber bundle, where:

- $B$ is the **base space** representing the domain of constraints, i.e., the parameter space of admissible configurations defined by $\mathcal{C} = (C_s, C_e, C_p)$;
- $E$ is the **total space** of effects, responses, or observable structures that emerge under instantiation of these constraints;
- $\pi$ is the projection mapping each effect in $E$ to its underlying constraint configuration in $B$.

**Definition 4.** *A scientific law $\mathcal{L}$ is modeled as a smooth section $s : B \to E$ such that $\pi \circ s = \mathrm{id}_B$, representing a consistent assignment of effects to constraint configurations.*

However, not all sections correspond to genuine laws. For a section $s$ to qualify as a law, it must satisfy a further condition: it must be *flat*, i.e., exhibit zero holonomy, over a suitable subdomain of $B$. This encodes the requirement that the law remains stable under transport along admissible paths within the constraint manifold, and is invariant under local deformations of constraint configurations.

**Definition 5.** *Let $\nabla$ denote a connection on $E$. A section $s$ is said to be a* law *over domain $D \subseteq B$ if it is flat with respect to $\nabla$ on $D$, i.e., the holonomy group along all loops in $D$ is trivial, and $\nabla s = 0$ along admissible directions in $D$.*

This geometric condition captures the idea that laws are stabilized structures: they admit no curvature in the sense of dynamical deviation under constraint variation. Where holonomy is nontrivial, we are in the presence of a regime where lawhood fails to persist, i.e., the law is either inapplicable or transitions into a different effective structure.

The fibered interpretation provides a rigorous setting for stratifying lawhood across domains. In particular:

- A **universal law** would correspond to a global flat section, rare or non-existent in practice;

- A **domain-specific law** corresponds to a flat section over a restricted open set $D \subset B$;
- A **piecewise law** corresponds to locally flat sections patched via gluing data across overlapping charts, potentially with transition functions between regimes.

This framework aligns with geometrical formulations in contemporary physics, where gauge theories, general relativity, and bundle-based formulations of quantum field theory all model physical structure in terms of local sections, connections, and curvature (Bain, 2003; Weatherall, 2011). It also resonates with the insight that laws are not rigid platonic truths but operationally stable morphisms in a structured manifold of constraints. Thus, within a structural ontology, the law is not a sentence or axiom, but a stabilized mapping over a constraint base, a topologically sensitive, holonomy-restricted section that persists where actualization is dynamically coherent.

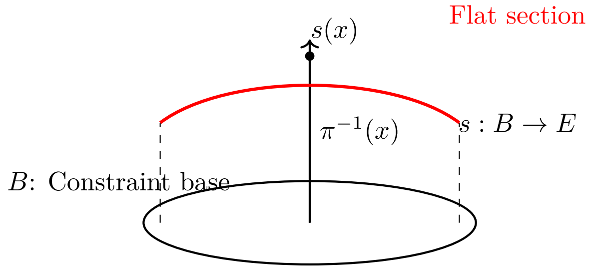


Figure 1: Illustration of a scientific law as a flat section $s : B \to E$ over a constraint bundle $\pi : E \to B$, with minimal holonomy.

**Geometric Interpretation of Constraint-Stabilized Laws**

Scientific laws are modeled as *sections* of a constraint bundle $\pi : E \to B$, where $E$ is the space of effectual states and $B$ is the base space of constraint configurations. A section $s : B \to E$ assigns to each constraint configuration $b \in B$ a consistent effect $s(b) \in E$, such that $\pi(s(b)) = b$. In this sense, the law is not a universal relation but a rule that stabilizes the projection of constraints into effects.
A *connection* on the bundle specifies how local changes in constraints propagate through $E$. It defines a notion of *parallel transport*, determining how effects vary consistently as one moves in $B$.

A section is said to be *flat* if it is preserved under parallel transport: it exhibits no *holonomy*, i.e., no net deviation after traversing a closed loop in the constraint space. This implies that the law remains structurally coherent throughout the domain.

Flatness thus encodes the global stabilizability of a law: the law is not merely locally compatible, but globally integrable across the regime. In this way, the geometric formalism clarifies the ontological thesis: laws are not primitive entities, but sections stabilized by the constraint architecture over structurally coherent domains.

## 4.2 Typology of Laws

The structural conception of scientific laws as stabilized sections over constraint manifolds allows for a principled typology of lawhood. Rather than classifying laws according to their subject matter or syntactic form, we differentiate them based on the nature and degree of structural stabilization from which they arise. Specifically, laws can be distinguished according to the type of constraint residue they represent within the architecture of a given regime $\mathcal{C} = (C_s, C_e, C_p)$.

**1. Invariant Laws.** These laws emerge as residues of *structural symmetries* or *topological invariants* present in the formal architecture of the regime. They are typically associated with conservation principles, symmetry groups, and invariance under coordinate transformations. Noether's theorem is a paradigmatic example: conserved quantities arise from continuous symmetries of the action, rendering the law a residue of the geometrical invariance of the system (Noether, 1918; Brading and Brown, 2003). Invariant laws correspond to globally flat sections over high-symmetry regions of the base space $B$, and they exhibit strong commutativity under actualization.

**2. Dynamic Laws.** Dynamic laws result from the *local stabilization* of constraint configurations under empirical and semantic projections. They are typically encoded in differential equations governing the evolution of systems under bounded regimes, e.g., the Schrödinger equation in quantum mechanics, or the Navier–Stokes equations in fluid dynamics. These laws are not derived from symmetry, but from the compatibility of local empirical invariants and projective constraints within a specific domain. The associated sections are flat only over restricted open subsets $D \subset B$, and their validity depends on the maintenance of dynamical coherence.

**3. Metastable Laws.** These laws are valid only within *regionally stabilized* regimes, often bounded by phase transitions, boundary conditions, or coarse-grained approximations. Examples include the equations governing solid-state behavior, effective field theories in condensed matter, or hydrodynamic laws in non-equilibrium systems. Such laws correspond to *piecewise flat sections*, whose domains of holonomy-triviality are limited and whose gluing across domains requires transition functions. Their lawhood is conditional and structurally fragile: they persist only as long as the constraint architecture remains within a metastable basin.

This typology emphasizes that scientific laws are not uniform in ontological status or epistemic scope. Their validity, stability, and explanatory power depend on the structural properties of the regimes from which they emerge. Laws are not classified according to subject-matter essentialism, but according to the mode of constraint-convergence and the nature of their residual invariance. Moreover, these types are not mutually exclusive. A given theory may involve overlapping layers of invariant, dynamic, and metastable laws, each operating at a different level of structural articulation. Recognizing this stratification avoids the reductionist temptation to treat all laws as either fundamental or derivative. Instead, it affirms the multiplicity and functional differentiation of lawhood across scientific domains.

### 4.3 Stratified Ontology of Law

The structural perspective developed throughout this article culminates in a reformulation of the ontological status of scientific laws. Rather than treating laws as universally valid entities or metaphysical constituents of nature, we propose a stratified ontology in which lawhood is understood as a *functional stabilization* within regime-relative architectures of constraint.

On this view, a law is not an independently existing object but a *stabilizing operator*, a section of minimal holonomy, that ensures the persistence of structured coherence across a constrained domain. Its ontological significance does not derive from its putative universality, but from the *persistence of its structural stability* under actualization. What is real, in this framework, is not the law itself, but the convergence dynamics that stabilize it. This position contrasts sharply with both classical metaphysics of laws and more recent ontic structural realist interpretations. In standard realism, laws are viewed as the fabric of the universe, either as relations between universals (Armstrong, 1983) or as primitive modal facts (Maudlin, 2007). In structural realism, laws are sometimes identified with invariant relational structures (Ladyman and Ross, 2007). Yet even in these approaches, lawhood retains a form of reification: it is an entity-like component of the world's ontology.

By contrast, the stratified ontology proposed here treats laws as *stabilization residues*: they mark the boundaries of constraint compatibility within layered domains. Invariant laws arise in high-symmetry strata; dynamic laws emerge in locally coherent fields; metastable laws define transitional zones of partial stabilization. Lawhood is thus not a monolithic predicate, but a stratified functional role indexed to the depth and robustness of constraint convergence. This ontology has two important implications. First, it explains the observed *domain-relativity* and *fallibility* of scientific laws without collapsing into instrumentalism. Laws fail not because they are false, but because the regimes that stabilize them dissolve under perturbation. Second, it grounds the explanatory power of laws not in their descriptive content, but in their capacity to maintain structural coherence across transformations, i.e., in their *commutation* *with actualization.*

Thus, a scientific law is real to the extent that it functions as a persistent stabilizer within a stratified constraint regime. Its ontological status is derivative but robust: not universal, but operationally irreducible within its domain of convergence. In this sense, laws are not windows onto metaphysical necessity, but functional residues of structural intelligibility.

# 5 Case Studies: Classical, Quantum and Relativistic Laws as Residues

## 5.1 Newtonian Dynamics: From Invariance to Residual Law

The classical law of motion expressed by Newton's second law, $F = ma$, is often regarded as a paradigm of universal lawhood. Traditionally interpreted as a fundamental principle governing the behavior of massive bodies, this formulation plays a central role in classical mechanics. However, within the framework of constraint-based structural ontology, $F = ma$ is better understood as a *residual projection* of a stabilized constraint regime, one that encodes invariance under specific kinematic symmetries.

More precisely, Newtonian dynamics emerges within a Galilean-invariant regime: the relevant structural constraints $C_s$ consist of invariance under Galilean transformations (translations, rotations, and boosts), with an absolute temporal structure and a flat Euclidean spatial geometry. The empirical constraints $C_e$ include reproducible measurements of acceleration, force, and inertial mass under laboratory conditions where external influences are negligible or controlled. Projective constraints $C_p$ require that motion be intelligible as the result of identifiable causes, and that the laws be predictive across similar physical scenarios. This triplet $\mathcal{C}_{\text{Newt}} = (C_s, C_e, C_p)$ defines a local constraint regime within which Newton's second law stabilizes as a persistent relation among observable quantities. The law $\mathcal{L}_{\text{Newt}}$, understood as a constraint residue, is thus:

$$\mathcal{L}_{\text{Newt}} := \text{Res}(\mathcal{C}_{\text{Newt}}) = \lim_{\epsilon \to 0} \Pi(\mathcal{C}_\epsilon)$$

This residual law is invariant under transformations that preserve the Galilean structure and fails to apply when that structure breaks down, for example, at relativistic speeds, in curved spacetime, or in quantum domains. Its domain of flat holonomy corresponds to the kinematic manifold of Galilean space-time, a structure topologically trivial and metrically rigid. Under this interpretation, $F = ma$ is not a metaphysical necessity, but a *projectible residue* that persists within a specific class of models satisfying the relevant constraints. It functions as a flat section over a domain $D \subset B$, where the base space $B$ parametrizes configurations of inertial frames and empirical conditions consistent with the Galilean regime. This analysis also reframes the concept of inertial mass: it is not an intrinsic metaphysical quantity, but a parameter whose constancy is stabilized under $\mathcal{C}_{\text{Newt}}$. The force term $F$ likewise depends on the constraint architecture: it is only measurable and definable where the system admits stable acceleration with respect to inertial coordinates.

Thus, Newton's second law exemplifies how a classical law can be interpreted not as a timeless governing entity, but as a dynamically stabilized, geometrically constrained projection, one that survives within the structured manifold of Galilean constraint coherence.

## 5.2 Schrödinger Equation: Constraint Stabilization in Quantum Systems

In the standard formulation of non-relativistic quantum mechanics, the Schrödinger equation is often regarded as the central dynamical law governing the time evolution of quantum systems. However, within a constraint-based ontology, its role is not to represent the fundamental behavior of nature per se, but to stabilize the structural conditions under which quantum phenomena become interpretable, projectible, and operationally coherent. The Schrödinger equation,

$$i\hbar\frac{\partial}{\partial t}\psi(t) = \hat{H}\psi(t),$$

is a differential expression defined over a Hilbert space, prescribing the unitary evolution of the state vector $\psi$ under a specified Hamiltonian operator $\hat{H}$. Its derivation and usage rely not only on formal axioms but on a set of interlocking constraints that structure the admissibility of measurement, superposition, and evolution.

From the constraint-based perspective, we identify the following triplet $\mathcal{C}_{\text{QM}} = (C_s, C_e, C_p)$:

- $C_s$: Structural constraints include the linearity of state space, unitarity of time evolution, and conservation of probability via the norm-preserving character of dynamics. These are often derived from Wigner's theorem and the group-theoretic invariance properties of the theory (Wigner, 1959; Weinberg, 1995).
- $C_e$: Empirical constraints correspond to the repeatable reproducibility of measurement outcomes under controlled preparation procedures, stabilized in laboratory contexts. These include the emergence of Born rule statistics and the compatibility of observed transitions with spectral decompositions (Busch, 2009).
- $C_p$: Projective constraints impose the requirement that quantum states support meaningful predictions, i.e., that they yield consistent probabilities, and that the theory preserves continuity between preparation, evolution, and measurement. In particular, the demand for uniqueness and completeness of evolution under measurement-induced constraints plays a central role (Redhead, 1987).

In this regime, the Schrödinger equation functions as a *constraint residue*: it is the form of evolution that remains stable under the combined imposition of structural symmetry, empirical reproducibility, and projective intelligibility. Unlike classical laws, its function is not to describe an external ontology of trajectories, but to coordinate the structure of interpretability across preparation and measurement contexts. This function aligns with views that emphasize the epistemic or inferential character of quantum dynamics, such as in the pragmatist interpretations of quantum theory (Healey, 2012), or the decoherence-based emergence of classicality within quantum subsystems (Zurek, 2003). What persists is not the ontological content of the wave function, but the stability of its dynamical form under the operative constraints of the theory.

Thus, the Schrödinger equation exemplifies a *projectively stabilized law*: it constrains the intelligibility and continuity of quantum modeling, rather than describing an objective process independent of measurement. Its lawhood is grounded in the robustness of functional coordination, not in representational accuracy.

### 5.3 Einstein Field Equations: Equilibrium of Constraint Dualities

In general relativity, the Einstein field equations (EFE) encode the dynamical coupling between spacetime geometry and energy-momentum distribution:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}.$$

Traditionally, this equation is interpreted as a fundamental law of nature, determining how matter tells spacetime how to curve, and conversely, how curvature governs the motion of matter. From the constraint-based perspective, however, the EFE is more accurately viewed as a *tensorial residue of compatibility*, a stabilizing equilibrium between dual regimes of structural constraint: one geometric, the other material. Formally, we identify the constraint regime $\mathcal{C}_{\text{GR}} = (C_s, C_e, C_p)$ as follows:

- $C_s$: Structural constraints include general covariance, Lorentzian signature, and differentiability conditions on the metric tensor $g_{\mu\nu}$. These constraints ensure that the dynamical laws are independent of coordinate choice and compatible with a pseudo-Riemannian geometry (Wald, 1984).

– $C_e$: Empirical constraints arise from gravitational phenomena such as light deflection, perihelion precession, gravitational redshift, and the behavior of compact astrophysical objects. These empirical regularities stabilize the operative parameters (e.g., mass, curvature) within observational tolerance (Will, 2014).

– $C_p$: Projective constraints enforce the global compatibility between the geometrization of gravitation and the localization of matter-energy. The theory must reconcile the conservation of energy-momentum ($\nabla^\mu T_{\mu\nu} = 0$) with the Bianchi identities for curvature ($\nabla^\mu G_{\mu\nu} = 0$), thereby ensuring that both sides of the field equations respect a shared differential structure.

Within this regime, the Einstein field equations emerge as a *residual tensor field* that stabilizes the compatibility between the geometric structure $G_{\mu\nu}$ and the material structure $T_{\mu\nu}$. The equation does not enforce a one-sided determination (from matter to geometry or vice versa), but expresses an *equilibrium constraint*: the mutual adjustability of curvature and energy-momentum under the governing symmetries and conservation laws. This equilibrium structure can be represented geometrically as a section $s : \mathcal{B} \to \mathcal{E}$ in a fibered space where $\mathcal{B}$ is the base of compatible background geometries and $\mathcal{E}$ the total space of dynamical field configurations. The Einstein equations specify the flatness condition $\nabla s = 0$ with respect to a connection enforcing conservation and covariance. The lawhood of the EFE is thus encoded in the preservation of this equilibrium under admissible variations of both geometry and matter.

Such an interpretation aligns with structural realist views that regard spacetime structure and matter distribution as co-dependent (Brown, 2005; Curiel, 2017). It also resonates with the idea that general relativity is not a theory about gravitational forces per se, but about the compatibility of tensor fields under constraint-encoded curvature (Rickles, 2008). In this framework, the Einstein equations are not axiomatic, but regime-stabilized. They persist as long as the dual constraint architectures, metric and matter, remain symmetrically compatible. Where this balance breaks down (e.g., at singularities, phase transitions, or in quantum gravity regimes), the equation ceases to define a stabilized law. The EFE thus exemplifies a law whose domain of validity is coextensive with the internal consistency of the dual constraint systems it harmonizes.

### 5.4 Empirical Horizons and Structural Transitions

While the present account refrains from grounding lawhood in direct empirical observables, it nonetheless opens avenues for indirect empirical sensitivity. Specifically, structural transitions in constraint regimes, such as those occurring in phase transitions, domain bifurcations, or topological reconfigurations, may reveal residual incompatibilities detectable via violations of holonomy, loss of section flatness, or breakdowns of local commutativity. For instance, the breakdown of effective laws at critical points in condensed matter systems (e.g., emergence or dissolution of quasi-particles in topologically ordered phases) may be interpretable as structural transitions where a law ceases to commute with the actualization operator of a regime boundary. Similarly, abrupt shifts in the Einstein field equations' applicability near singularities or in quantum gravity regimes could reflect the collapse of residual compatibility across overlapping constraint regimes.

Such phenomena do not falsify the existence of laws per se, but rather signal that the regime-relative stability conditions required for residuation no longer hold. This provides a testable prediction: where regimes fragment or interpenetrate incoherently, laws cease to stabilize, and empirical behavior loses its local structural predictability.

## 6 Implications for Scientific Realism and Explanation

### 6.1 Structural Realism Revisited: From Relations to Residues

Ontic Structural Realism (OSR) has emerged as a leading position in contemporary philosophy of science, proposing that the ultimate ontology of the physical world consists not in objects with intrinsic identity, but in relational structures (Ladyman and Ross, 2007; French and Ladyman, 2003). In this view, structure, not substance, is the primitive explanatory element, and the laws of nature are expressions of these invariant structural relations.

However, while OSR succeeds in displacing object-based metaphysics, it often leaves underdeveloped the operational genesis and stratification of structure itself. What remains obscure is how structure arises, stabilizes, and becomes scientifically intelligible. If structure is ontologically primitive, how are its empirical and explanatory functions mediated? What determines its domain of validity or its capacity for projection across models and regimes? The constraint-based framework developed here proposes a refinement of OSR: one in which structure is not a metaphysical given, but a *constrained regime of compatibility*, and scientific laws are not direct manifestations of global structure, but *projectible residues* stabilized within such regimes. On this view, structure is regime-relative: it is constituted by the convergence of invariance conditions (structural), empirical stability (experimental), and intelligibility requirements (projective). A law is not simply a relation within this structure, but the persistent output of its stabilization, a feature that commutes with the dynamics of actualization within a domain. This reformulation shifts the ontological focus from structural relations per se to the conditions under which such relations are stabilized and made resilient.

This move from *structure as primitive* to *structure as constrained regime*, and from *law as invariant relation* to *law as residual stabilizer*, offers several advantages:

1. It anchors structural realism in the operational logic of theory formation, rather than in abstract metaphysical commitments.
2. It allows for stratification: some structures and laws are more robust or deeply stabilized than others, depending on their place in the constraint hierarchy.
3. It dissolves the dilemma between realism and instrumentalism: laws are neither metaphysical truths nor mere tools, but stabilized morphisms whose reality is indexed to their functional persistence.

In this reframed OSR, scientific realism no longer requires positing immutable structures or universal laws. It instead affirms the constrained emergence and regime-dependent stability of projectible invariants. What science reveals is not the blueprint of reality, but the architecture of compatibility that allows certain structural residues to persist, communicate, and generalize across domains.

## 6.2 Toward a Modal Ontology of Scientific Law

The structural conception of law developed in this article culminates in a modal reformulation of scientific ontology. Rather than positing laws as descriptions of what *is* or prescriptions of what *must be*, we propose to understand them as *operators of stabilization* within a structured space of what can become actual under regime-relative constraints.

Let $\mathcal{A}$ denote the space of admissible actualizations, i.e., the set of system configurations that can be stably instantiated under a constraint regime $\mathcal{C} = (C_s, C_e, C_p)$. A law $\mathcal{L}$, as we have defined, is a constraint residue that selects, projects, or filters invariant structures within $\mathcal{A}$. Formally, we interpret the law as a morphism:

$$\mathcal{L} : \mathcal{A} \to \mathcal{A}$$

such that $\mathcal{L}$ stabilizes the subset of configurations that commute with the constraint-induced actualization operator $\mathrm{Act}_D$. That is,

$$\mathcal{L} \circ \mathrm{Act}_D = \mathrm{Act}_D \circ \mathcal{L}$$

This reflects the condition introduced in the Structured Actualization Theorem (Section 3.3) and anchors lawhood in the modal preservation of actualizability. Within this framework, the modal status of laws is not defined by a global necessity (as in Kripkean metaphysics), nor by statistical robustness (as in Humean regularism), but by *stabilization under directional constraint flows*. The relevant modality is not timeless necessity, but *oriented compatibility*: the law is what ensures that certain transitions, evolutions, or responses remain coherent within a domain.

To formalize this, one can invoke a logic of constrained actualization $\mathcal{L}_{\Box}^{\rightarrow}$, in which modal operators are relativized to constraint regimes and directionality of realization:

- $\Box_{\mathcal{C}}\phi$ reads: "$\phi$ is stabilized in all admissible actualizations under $\mathcal{C}$";
- $\phi \rightsquigarrow_{\mathcal{C}} \psi$ expresses: "under regime $\mathcal{C}$, actualizing $\phi$ leads to a stabilized actualization of $\psi$";

In this logic, laws are those formulas $\mathcal{L}$ for which:

$$\forall \phi \in \mathcal{A}, \quad \Box_{\mathcal{C}}(\phi \rightsquigarrow_{\mathcal{C}} \mathcal{L}(\phi))$$

That is, $\mathcal{L}$ preserves the modal structure of constrained actualization: it ensures the coherence and reproducibility of transitions across admissible states. This modal ontology has the virtue of grounding the lawhood of scientific principles not in metaphysical absolutism, but in operational stability, directional coherence, and constrained realizability. It accommodates the empirical fact that laws vary across regimes, yet retains a principled account of their functional necessity. It also permits the articulation of multiple levels of modality: local, global, structural, and projective. Laws can be weakly modal (domain-bound), strongly modal (inter-regime stable), or dynamically modal (stabilizing transformations). Such stratification aligns with the layered architecture of contemporary physics and the multifaceted role of laws in explanation, modeling, and prediction.

In this view, scientific laws are not about possible worlds simpliciter, but about the structured actualization of physical configurations within constraint-encoded topologies. Lawhood becomes a property of morphisms in the modal dynamics of constrained possibility, neither reductively factual nor metaphysically imposed, but structurally necessitated.

**Formal Framework: Oriented Modal Logic of Constrained Actualization**

To sharpen the modal framework introduced above, we outline a minimal axiomatization of the logic of constrained actualization. This logic, denoted $\mathcal{L}_{\Box}^{\rightarrow}$, interprets modalities relative to constraint regimes $\mathcal{C}$, and directional transitions between actualizable states.

Let $\phi, \psi \in \mathcal{A}$ be admissible actualizations under regime $\mathcal{C}$, and let:

- $\Box_{\mathcal{C}}\phi$ mean "$\phi$ is stabilized under all admissible trajectories in $\mathcal{C}$";
- $\phi \rightsquigarrow_{\mathcal{C}} \psi$ mean "$\phi$ gives rise to $\psi$ under actualization flows governed by $\mathcal{C}$".

We postulate the following axioms:

**(Ref) Reflexivity of Stabilization:**

$$\Box_{\mathcal{C}}\phi \to \phi$$

A stabilized actualization is in particular admissible.

**(Mon) Monotonicity:**

$$\phi \to \psi \;\Rightarrow\; \Box_{\mathcal{C}}\phi \to \Box_{\mathcal{C}}\psi$$

If $\phi$ implies $\psi$, then stability of $\phi$ implies stability of $\psi$.

**(Trans) Constraint Persistence (optional):**

$$\Box_{\mathcal{C}}\phi \to \Box_{\mathcal{C}}\Box_{\mathcal{C}}\phi$$

This axiom holds only if the regime $\mathcal{C}$ is *directionally isotropic*, i.e., stabilization is temporally symmetric or iteration-stable. In general, for anisotropic or dynamically stratified regimes (e.g. irreversible processes), this axiom may fail.

**(Comm) Commutativity of Actualization with Law:**

$$\Box_{\mathcal{C}}(\phi \rightsquigarrow_{\mathcal{C}} \mathcal{L}(\phi))$$

This expresses the modal invariance of the law under admissible actualizations (cf. Section 3.3).

This system defines a logic that is neither Kripkean (i.e., based on arbitrary accessibility between possible worlds), nor purely dynamic in the sense of Propositional Dynamic Logic (PDL), but belongs to a class of *constraint-grounded modalities*.

Topologically, this logic is closer to neighborhood semantics or sheaf-theoretic modalities, where stability is defined relative to open covers or admissible deformations (Abramsky and Vickers, 1993). Semantically, the operator $\Box_{\mathcal{C}}$ acts as a filter selecting structurally invariant actualizations under perturbation or projection within the regime. This orientation justifies the asymmetry of modal force in physical regimes: stabilization is not necessarily closed under reversal, and laws hold only where the constraint architecture preserves directed coherence.

## 6.3 Scientific Explanation Without Governing Laws

In classical models of scientific explanation, particularly in the deductive-nomological tradition (Hempel and Oppenheim, 1948), a phenomenon is explained by subsuming it under a general law and deriving its occurrence from initial conditions. This framework treats laws as governing principles: causes that produce effects by logical necessity. However, such models face longstanding difficulties, including issues of asymmetry, contextuality, and the explanatory irrelevance of mere derivability (Salmon, 1989; Woodward, 2003).

The structural ontology proposed here rejects the conception of laws as governing causes. Instead, scientific laws are interpreted as *constraint operators*, residual structures that stabilize the coherence of a regime, not mechanisms that enforce outcomes. On this view, explanation is not an inference from a general principle, but a reconstruction of the constraint architecture that makes a given phenomenon possible and intelligible. This view converges with the longstanding critique of governing laws articulated by Cartwright, who argues that the laws of physics "lie" in the sense that they do not straightforwardly describe empirical phenomena, but operate as idealized constructs selectively applied across contexts (Cartwright, 1983). Rather than seeking universal truth, laws function as instruments within model-mediated inference frameworks.

Similarly, Giere emphasizes that scientific theories do not provide direct representations of reality, but rely on *model-based reasoning*, in which abstract structures are fitted to specific domains via context-sensitive constraints (Giere, 1988). In this light, laws are not ontological claims but structured constraints that support explanatory and predictive coherence within limited regimes. Our approach formalizes this by identifying laws with the stabilized outputs of convergent constraint architectures. Hence, the constraint-residue model provides a structural and modal grounding for insights already expressed in empiricist and pragmatic philosophies of science: laws gain their efficacy not from universal scope, but from localized stabilization, coherence, and functional projection.

More precisely, to explain a phenomenon $P$ is to identify the minimal constraint regime $\mathcal{C}_P = (C_s, C_e, C_p)$ under which $P$ becomes an admissible and stable actualization. The law involved is not the cause of $P$, but the operator $\mathcal{L}$ that ensures the compatibility of $P$ with the operative structure of the domain:

$$\text{Explain}(P) := \text{Reconstruct } \mathcal{C}_P \text{ such that } \mathcal{L}_{\mathcal{C}_P} \circ \text{Act}_D(P) = \text{Act}_D \circ \mathcal{L}_{\mathcal{C}_P}(P)$$

This perspective aligns with recent interventionist and mechanistic accounts of explanation, but goes further by shifting the focus from causal processes to the structural admissibility of configurations (Woodward, 2003; Craver, 2007). What explains is not a sequence of events governed by law, but a web of constraints that make the observed configuration robust, intelligible, and stable under perturbation. Moreover, this view accommodates the non-universality and domain-relativity of explanation. Laws that apply in one regime may fail in another, yet explanations remain possible as long as the local constraint architecture can be reconstructed. This avoids both the excesses of universalism and the relativism of purely phenomenological accounts.

Scientific explanation does not require laws as causes or universals. It requires constraint regimes that stabilize intelligibility. Laws contribute to explanation not by governing phenomena, but by marking the structural invariants that delimit what can coherently occur under specified constraints. To explain is to make visible the modal. This perspective also invites a reassessment of the epistemic status of laws in model-based science. Rather than being epistemic targets in themselves, laws, understood as constraint residues, function as *epistemic affordances* (Rouse, 2002), enabling navigation within structured spaces of inference, intervention, and idealization. In this respect, scientific laws are best viewed as stabilizers of *model-resonance zones*: domains where different modeling practices converge upon structurally robust regularities. The explanatory value of a law depends not on its universality, but on its capacity to coordinate models, data, and instruments across experimental regimes.

Such a view aligns with pluralist epistemologies that emphasize the role of representation, measurement, and disciplinary integration in the construction of scientific coherence (Massimi, 2022; Leonelli, 2016). It also complements perspectival approaches that frame laws as contextually embedded in local inferential and experimental cultures (Giere, 2006). Our constraint-theoretic framework provides an ontological backbone to these pluralist perspectives: it explains why local convergence and model-coordination are possible, by grounding them in shared architectures of constraint. In doing so, it reconciles the operational success of science with a realist account of structural stabilization, without appealing to universal lawhood.

# 7 Anticipating Objections and Delimiting Scope

No structural reformulation of scientific ontology can avoid confronting traditional expectations associated with the metaphysical status of laws. This section considers three potential objections to the constraint-based perspective defended in this article and provides principled responses that delimit its scope while clarifying its commitments.

## Objection 1: "You merely replace a universal entity with an ad hoc emergence."

A natural concern is that, by rejecting laws as universal governing entities, the present account risks replacing a unified explanatory structure with a collection of ad hoc, regime-specific emergences. If laws are residues of contingent constraint configurations, how can they exhibit the stability and cross-domain applicability expected of genuine scientific laws?

**Response.** This objection underestimates the convergent architecture of constraint regimes. A law, on this view, is not arbitrarily emergent but stabilized across overlapping domains through the convergence of structural, empirical, and projective constraints. What guarantees its robustness is not a metaphysical fiat, but the redundancy of stabilization pathways: the same invariant structure arises from multiple constraints acting in concert. This convergence explains both the internal coherence of the law and its domain-relative stability across contexts. Far from ad hoc, the emergence of a law reflects the deep structure of constraint compatibility. Moreover, this stratified emergence allows for precise empirical delimitation: laws are valid exactly where the constraint manifold retains flat holonomy. Their stability is not assumed, but conditionally derived from the architecture of actualization. This makes their emergence tractable, testable, and revisable, unlike metaphysically postulated universal laws.

## Objection 2: "What about mathematical laws?"

A further objection targets the apparent inapplicability of the constraint-residue model to mathematical laws. Equations such as the Laplace equation, the Fourier transform, or the general form of differential equations do not arise from empirical stabilization but are derived from internal axiomatic and logical consistency. Does the present account exclude such laws from scientific ontology?

**Response.** The distinction is essential. Mathematical laws are not laws in the empirical sense, but *formal structures* defined within internally coherent symbolic systems. They exhibit necessity by virtue of syntactic derivability, not empirical stability. In the constraint-theoretic framework, such laws correspond to what might be called *structural invariants* rather than *residues*. Indeed, their function in science is not to constrain physical systems directly, but to provide the formal scaffolding through which constraint regimes become expressible. They define the invariant background space (e.g., Hilbert spaces, differentiable manifolds, algebraic structures) in which empirical regularities are modeled. As such, they are part of the $C_s$ layer, structural constraints, rather than the full constraint regime $\mathcal{C} = (C_s, C_e, C_p)$. This distinction echoes themes in recent philosophy of mathematics and physics, where the epistemic and functional role of mathematics is emphasized over its ontological commitment (Baker, 2005; Bueno and Colyvan, 2011). Mathematical laws are necessary within the structures they define, but their applicability to the world depends on the embedding of physical systems into those structures via empirical and projective constraints.

Therefore, mathematical laws are not residual, they do not emerge from convergence across empirical regimes, but *structural by definition*. They are preconditions of representation, not stabilized outputs of actualization. Their necessity is syntactic, their generality topological, and their role foundational, not empirical.

### Objection 3: "This weakens the explanatory power of laws."

A final objection holds that reconceiving laws as domain-relative residues of constraint regimes diminishes their explanatory force. If laws are no longer universal or governing, how can they sustain the explanatory ambitions of science, particularly the unification of diverse phenomena and the derivation of predictive content?

**Response.** This objection rests on a misconception of what makes scientific explanation powerful. Explanatory strength does not stem from the metaphysical status of laws as universal edicts, but from their capacity to reveal the *modal scaffolding* underlying observed regularities. By grounding laws in convergent constraint architectures, the present account restores explanation to its constructive root: not what follows from the law, but how the law itself is made possible. In this sense, the explanatory role of laws is enriched, not diminished. Rather than being opaque governing entities, laws become transparent stabilizers whose form reflects the intelligible architecture of empirical coherence. Explanation, then, is not the application of a law, but the reconstruction of the constraint regime that renders the phenomenon both admissible and stable. This view is consistent with structural and mechanistic accounts of explanation, which emphasize the role of organizational architecture and structural dependencies over general entailments (Craver, 2007; Glennan, 2017). It also aligns with interventionist perspectives, which define explanatory relevance in terms of stability under manipulation, not derivability from fixed principles (Woodward, 2003).

By relocating the source of explanatory force from metaphysical necessity to structural genesis, the constraint-based model does not weaken explanation, it clarifies and deepens it. What explains is not that a law holds universally, but that it stabilizes an otherwise unstructured domain. This approach thus reconnects explanation with scientific practice: it reflects how laws are found, stabilized, and projected, not assumed.

## 8 Conclusion: Law Without Law, Structure Without Universality

This article has argued for a reconceptualization of scientific laws not as metaphysical arbiters of reality, nor as compact descriptions of empirical regularities, but as residual stabilizations emerging from convergent regimes of constraint. Against both nomological realism and Humean supervenience, we have proposed that laws are neither primitive nor epiphenomenal, but *projectible residues*, structures that persist under the compatibility conditions defined by interlocking structural, empirical, and projective constraints. This view reorients the ontology of science around the architecture of constraint rather than around axiomatic necessity. It dissolves the dichotomy between governing laws and observational regularities by showing how both emerge as stratified outputs of deeper compatibility structures. In doing so, it offers a middle path: neither metaphysical absolutism nor pragmatic deflation, but a modal ontology grounded in the operational coherence of actualizable configurations.

We have shown that laws differ in type, some invariant, some dynamic, some metastable, depending on the depth and breadth of the constraint regimes that stabilize them. Their explanatory power does not derive from logical derivability or universal applicability, but from their role in maintaining the structural coherence of scientific domains. To explain a phenomenon is not to invoke a law as cause, but to reconstruct the regime under which it becomes stably intelligible. Finally, we have proposed a modal framework in which laws are operators in the space of admissible actualizations. This opens the way to a non-Kripkean, structurally grounded logic of scientific modality, one in which the necessity of laws is indexed not to possible worlds, but to the persistence of constraint under actualization.

In this sense, the scientific law is no longer the timeless ruler of a lawful universe. It is a stabilized trace of structural convergence, a *law without law* in Wheeler's sense, but one that regains intelligibility and testability through the rigor of constraint theory. Likewise, structure ceases to be universal and becomes stratified, directional, and context-sensitive: a *structure without universality* that remains real precisely because it is operationally grounded. Scientific laws, on this account, are not authoritative dictates imposed upon nature, but operational residues of the regimes that stabilize scientific intelligibility. Their reality lies not in metaphysical governance, but in structural persistence under constraint. What results is an ontology of law without governance, but not without structure.

# Outlook

This paper has proposed a structural ontology of scientific lawhood grounded in the notion of constraint residues, stabilized invariants emerging from the interplay of structural, empirical, and projective regimes. Rather than treating laws as metaphysical primitives or descriptive generalizations, we have argued for their interpretation as regime-relative stabilizations that ensure local coherence and projectibility. This account offers explanatory traction for a wide range of scientific laws, from invariant conservation principles to metastable behavioral regularities. However, several limitations and perspectives for extension remain. First, while the current formalism draws heavily from mathematical physics, future work should examine how constraint residues function in domains where the structural articulation of models is less explicit, such as evolutionary biology, cognitive science, or climate dynamics. Second, a more detailed integration of epistemic practices, such as model calibration, simulation design, or experimental heuristics, would enrich the account of projective constraints beyond their current abstract form. Third, the relation between constraint residues and explanatory pluralism across disciplines suggests a possible application to the social sciences, where law-like regularities are often context-dependent and structurally discontinuous.

In all cases, the constraint-based framework invites further development as a general theory of lawhood grounded in the stability of intelligibility rather than the unity of ontology.

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