Observer-Invariant Distinguishability as a Separation Principle for Physical Theory

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For the General Reader

Physics describes the world, but every physical theory contains apparatus that is purely bookkeeping — choices of coordinates, conventions, or representational features that have nothing to do with what is actually out there. How do we tell what is physics and what is bookkeeping?

This paper argues that the answer is not a matter of taste. There is a single principle — *Observer-Invariant Distinguishability* (A0) — that fixes which features of any physical theory carry real physical content: those that all admissible observers agree on. Features that vary depending on the observer or the description belong to the bookkeeping.

The paper makes three claims about this principle.

First, it is not optional. A theory that violates A0 cannot define measurement outcomes, information content, or predictive laws as facts about the world; it produces only observer-relative reports that do not combine into shared empirical predictions. We prove this as a formal theorem.

Second, it is already silently at work inside our most successful theories — general relativity and quantum mechanics — without which their equations cannot be physically interpreted. The metric components of GR and the state vectors of QM are not themselves physical content; their physically meaningful invariants are. Without that separation, GR collapses into coordinate convention and QM acquires unmeasurable degrees of freedom.

Third, when combined with substantive premises about the substrate of physical reality (an ontology of irreversible "commitment events" developed in companion papers), A0 helps isolate familiar structures of physics — Lorentz invariance, the weak equivalence principle, the Hilbert-space structure of quantum mechanics — from broader candidate spaces. A0 does not generate these structures by itself. What it does is eliminate alternatives that fail invariance, leaving only what survives the test of agreement across observers.

The principle is therefore neither trivial nor omnipotent. It marks, sharply, the dividing line between what counts as a physical fact and what counts as a feature of how we describe one.

Abstract

Physical theories are commonly assumed to describe an observer-independent reality. This assumption is rarely formalised, and when it is, it is treated as philosophical rather than structural. We make the assumption explicit, formalise it as a working principle, and develop both its negative and positive content.

The negative content is a *necessity theorem*: any theory that assigns physical content to distinctions not invariant under admissible observer transformations fails to define a consistent notion of measurement, information, or predictive law. We give the theorem with a sketch proof and a minimal counterexample.

The positive content is a separation reading: A0 partitions the apparatus of a theory into representational surplus and physical content, and — when combined with explicit auxiliary premises — acts as a *projective sieve* that selects familiar structures (Lorentz invariance, invariant causal order, the weak equivalence principle, relational pre-commitment quantum structure) from broader candidate spaces. We are careful to identify, in each case, what premises supply structure and what role A0 plays in eliminating non-invariant alternatives.

The paper aims for the version of the foundational claim that is defensible rather than the strongest one statable: A0 is a *necessary condition* for physical theory, not by itself a *derivation* of physical theory.

Table of Contents

Part I — A0 as a Separation Principle

1. Introduction 1.1 Scope 1.2 Roadmap
2. Admissible Observers 2.1 Operational definition 2.2 Avoiding circularity 2.3 What this excludes
3. What Counts as a Physical Fact 3.1 The agreement criterion 3.2 What A0 does *not* say
4. The Necessity Theorem 4.1 Statement 4.2 Sketch proof 4.3 Example: observer-dependent fact assignment 4.4 Generalisation beyond function-based measurement
5. Failure Modes Without A0 5.1 Collapse of measurement 5.2 Breakdown of information 5.3 Loss of predictive laws 5.4 Note on relational interpretations
6. A0 as a Separation Principle: Formalisation 6.1 Equivalence classes 6.2 Statement (formal) 6.3 What A0 does
7. Relation to Gauge Invariance and Relational Interpretations 7.1 A0 vs. gauge invariance 7.2 Relational interpretations

Part II — A0 as a Projective Sieve

8. From Implicit Assumption to Explicit Principle 8.1 A0 in the VERSF Programme

9. A0 as a Projective Sieve 9.1 Lorentz invariance over Galilean 9.2 Invariant causal order 9.3 Universal gravitational coupling 9.4 Relational pre-commitment quantum structure 9.5 Why GR and QM cannot function without A0
10. Summary: What A0 Does and Does Not Do
11. Conclusion
12. Anticipated Questions and Objections

References

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1. Introduction

Modern physics rests on an implicit assumption: that there exists a distinction between what is physically real and what is merely a feature of description. Coordinates, gauge representations, and observer conventions may vary, but the underlying physical content is taken to be invariant under an appropriate equivalence.

This assumption is rarely stated explicitly as a global principle. Yet the cost of permitting its violation is severe:

A theory that permits observer-dependent facts cannot define measurement outcomes, and therefore cannot function as a physical theory.

The assumption is more often implemented case-by-case — as gauge invariance in electromagnetism, diffeomorphism invariance in general relativity, the unobservability of global phase in quantum theory — without the underlying common commitment being named. We propose to name it.

A0 (Observer-Invariant Distinguishability): *Physical content depends only on distinctions invariant under all admissible observer descriptions.*

The operational bite of A0 is sharper than its abstract form suggests. We will show in §4 that:

Any theory that violates A0 cannot define measurement outcomes uniquely, cannot define information content as a fact, and cannot define predictive laws with definite inputs and outputs.

A0 is therefore not a stylistic preference for invariance; it is a precondition for the operational vocabulary of physics — measurement, information, prediction — to refer to anything at all. A theory that violates A0 does not merely choose a different ontology; it loses the resources to specify what its own predictions are.

Two clarifications are needed before this principle can do work.

First, A0 does not say that observer-dependent formalism is forbidden. It says that whatever physical claims a theory makes must reduce to claims about invariants under the equivalence relation generated by changes between admissible observers. Formalism that varies under such changes (potentials, coordinates, phases) is welcome; it simply does not, on its own, carry physical content.

Second, A0 is not, on its own, a generator of physical structure. It is a *projection*. When combined with explicit auxiliary premises — about the substrate of facts, the dynamics of commitment, the geometry of representation — A0 isolates a unique surviving structure by removing candidates that fail invariance. The auxiliary premises supply the structure; A0 selects from it.

1.1 Scope

We adopt the following operative definition throughout: *a physical theory is one that assigns observer-independent empirical content to its formal states*. Theories that fail to do so may be coherent as formal systems but fall outside this paper's scope. The necessity claims that follow are claims about physical theories in this sense.

This paper does not claim that A0 uniquely determines physical law. Specific structures — the Lorentz group, the weak equivalence principle, complex Hilbert space — emerge only when A0 is combined with substantive auxiliary premises about the substrate, dynamics, and representation. What this paper claims is narrower and stronger:

Any theory that violates A0 cannot function as a theory of observer-independent physical facts.

A0 is a *necessary condition* for physical theory. It is not, by itself, a *derivation* of physical theory.

1.2 Roadmap

Part I (§§2–7): A0 as a separation principle.

- §2 specifies what counts as an admissible observer.
- §3 states the criteria for physical facthood.
- §4 proves the *necessity theorem*: A0 is required for measurement to be well-defined.
- §5 elaborates the failure modes when A0 is violated.
- §6 gives the formal apparatus (equivalence classes under the group of admissible observer transformations).
- §7 distinguishes A0 from gauge invariance and addresses relational interpretations.

Part II (§§8–11): A0 as a projective sieve.

- §8 traces A0 across implicit usage in modern physics and positions it within the VERSF programme.
- §9 deploys A0 in four specific derivations: Lorentz invariance, invariant causal order, the weak equivalence principle, and relational pre-commitment quantum structure.
- §10 summarises what A0 does and does not do.

- §11 concludes.

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2. Admissible Observers

A0 quantifies over "all admissible observer descriptions." The principle is only as well-defined as that quantifier. We therefore specify it.

2.1 Operational definition

An **admissible observer description** is a representation of the substrate that:

1. **Records committed events** through a protocol that respects the substrate's commitment structure (i.e., does not retrospectively undo commitments or invent commitments that did not occur);
2. **Uses local resources** — finite memory, finite communication, finite measurement precision — that no other admissible observer is excluded from using;
3. **Differs from another admissible description only by transformations that preserve the set of commitment-event records**, possibly relabelling them.

Concretely: two descriptions are inter-admissible if there is a transformation between them that maps each commitment event to itself (or to a uniformly relabelled version of itself) and preserves the irreversible-ordering structure on commitment events.

2.2 Avoiding circularity

This definition does not appeal to "what counts as a fact" — it appeals to commitment events, which are independently characterised as substrate-level irreversible records. The equivalence among admissible observers is therefore not "observers who agree on facts" (which would be circular) but "observers whose representations are related by commitment-preserving transformations."

Stated structurally: *admissibility is defined via transformations preserving record-structure and ordering constraints, not via agreement on values; the equivalence relation is specified prior to, and independently of, the notion of facthood.*

A0 then acquires bite: it says that the physical content of a theory consists of those quantities invariant under the equivalence generated by such transformations, and *not* of quantities that vary under them.

2.3 What this excludes

- Descriptions that posit additional facts beyond commitment events (these would be carrying surplus structure that A0 marks as non-physical).

- Descriptions that erase commitment events that did occur (these violate the substrate-respecting condition).
- Descriptions privileged by parameters no other admissible observer can access (these violate the local-resources condition).

The class of admissible observers is thereby specified independently of the conclusions A0 will be used to draw.

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3. What Counts as a Physical Fact

A physical theory aims to describe facts about the world. We require, minimally, that a fact satisfy:

- **Definiteness** — it corresponds to a specific outcome or state.
- **Stability** — it persists in a form accessible to multiple observations.
- **Agreement** — it is not dependent on arbitrary features of the description.

The third condition is the substantive one and is what A0 makes precise.

3.1 The agreement criterion

Consider a quantity X that two admissible observers assign different values to:

O_1: X = a, O_2: X = b, $a \neq b$.

If both assignments are physically valid, then X has no unique value. It cannot be:

- *measured* — measurement requires a unique outcome to register;
- *recorded* — a stable record requires a definite value to record;
- *predicted* — prediction requires an input–output relation, and the input here lacks a definite value.

Such a quantity therefore fails one or more of the conditions for facthood. A0 says: such a quantity is not physical content.

3.2 What A0 does *not* say

A0 does not say that X as a *formal object* must be removed from the theory. Vector potentials, coordinate values, and unphysical phase factors all vary across admissible observers, and physics uses them constantly. A0 says only that the *physical content* of the theory does not include them — it includes only their invariants.

This is the separation principle reading: A0 partitions formalism into representational and physical, and asserts that only the invariants carry facts.

4. The Necessity Theorem

Sections 2 and 3 set up the conceptual machinery: admissible observers and the criteria for physical facthood. We now show that A0 is not merely a stylistic preference for invariance but a formal necessity. A theory that violates A0 cannot consistently define measurement.

4.1 Statement

Let $\mathcal{S}$ denote the formal state space of a candidate physical theory, $\mathcal{O}$ the set of admissible observer descriptions in the sense of §2.1, and $\mathcal{V}$ a value space (the range of possible measurement outcomes for some quantity of interest).

A *measurement function* for a quantity Q is a function $M_Q: \mathcal{S} \to \mathcal{V}$ that assigns to each state a unique outcome.

Theorem (Necessity of Observer-Invariant Distinguishability). *Suppose a candidate physical theory T assigns physical content to a distinction D such that, for some state* $s \in \mathcal{S}$ *and some pair of admissible observer descriptions* $O_1, O_2 \in \mathcal{O}$*,*

$$O_1(s)|_D \neq O_2(s)|_D,$$

where $O(s)|_D$ *denotes the value of D in state s under observer description O. Then no observer-independent measurement function* $M_D: \mathcal{S} \to \mathcal{V}$ *for D is well-defined as a fact of T.*

The qualifier *observer-independent* is essential. The theorem does not deny that each observer can define their own measurement function $M_D^{(O_i)}$ relative to their own description; it denies that any single M_D exists that all admissible observers would agree is the measurement function of D. Without such an inter-observer-invariant function, no fact of the form "the measurement of D on s yielded outcome v" can be stated by T.

A theory in this position cannot define *shared empirical predictions*: claims of the form "all admissible observers will record outcome v" have no observer-independent content, since v itself varies by observer. The "observer-relative but consistent" position therefore fails to deliver physics — it delivers a collection of mutually unrelatable bookkeeping schemes, with no empirical claim that all admissible observers can verify against the world.

Compactly: *the theorem does not preclude observer-relative measurement maps* $M_{(O_i)}$*; it establishes that no observer-independent measurement map exists, and therefore no shared empirical prediction can be defined.* Observer-relative physics remains a coherent formal possibility; observer-independent physics requires A0.

4.2 Sketch proof

A measurement function M_D assigns, by definition, a unique outcome in $\mathcal{V}$ to each input state.

The hypothesis states that D's value in state s depends on the observer description: O_1 assigns one value, O_2 assigns another. If T treats this distinction as physical content, then both values are claimed as facts about s.

A function cannot return two distinct values for the same input. Therefore no M_D exists that is observer-independent.

It follows that T cannot, in any operationally well-defined sense, *measure* D. Since predictions about D require measurement to interpret outcomes, and information content requires distinguishability of outcomes to be assigned, T simultaneously loses the resources for prediction and for information content with respect to D.

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Corollary (Loss of operational meaning). A theory that violates A0 with respect to a distinction D cannot define:

- a unique measurement outcome for D,
- an observer-independent information content over D, or
- a predictive law F: $\mathcal{S} \to \mathcal{S}$ whose inputs and outputs are facts about D.

4.3 Example: observer-dependent fact assignment

The minimal failure case is concrete and instructive. Let $O_1, O_2 \in \mathcal{O}$ be two admissible observer descriptions. Let $s \in \mathcal{S}$ be a state. Let X be a quantity that T claims as physical content. Suppose:

$O_1(s)|$_X = a, $O_2(s)|$_X = b, $a \neq b$.

Then T contains the joint claim that "X(s) = a is a fact" and "X(s) = b is a fact." The operational consequences are:

- **No measurement.** No function M_X: $\mathcal{S} \to \mathcal{V}$ returning a unique value exists; both a and b are claimed as outcomes.
- **No information content.** The Shannon distinguishability between X = a and X = b is one bit per O_1 (which sees X = a as definite and X = b as a counterfactual) and one bit per O_2 (which sees the reverse). There is no observer-independent distinguishability between a and b for T to assign.
- **No prediction.** A law F taking X(s) as input has no unique input to consume; F(a) and F(b) are both candidate outputs without any fact selecting between them.

Therefore the theory T lacks a well-defined operational semantics: there is no consistent mapping from formal symbols to operational facts that all admissible observers would agree on.

This is the elementary failure A0 prevents. A0 is the requirement that no such case obtain for distinctions counted as physical content.

4.4 Generalisation beyond function-based measurement

The theorem of §4.1 was stated for measurement functions M_D: 𝒮 → 𝒱. The same argument extends to broader frameworks for measurement.

Generalised probabilistic theories (GPTs). In a GPT, measurement outcomes are defined by *effects* — linear functionals e acting on states ω ∈ Ω to produce outcome probabilities e(ω) ∈ [0,1]. If e is not invariant under admissible observer transformations, then e(ω) is observer-dependent: different admissible observers assign different probabilities to the same outcome–state pair. No shared probability assignment exists, and the GPT cannot define a unique probabilistic prediction as a fact.

Operator-based frameworks. In standard quantum theory, an observable is represented by a self-adjoint operator A, and its expectation value in state |ψ⟩ is ⟨ψ|A|ψ⟩. If A is not invariant under the relevant group of admissible transformations (for QM, at minimum the global phase action |ψ⟩ ↦ e^(iθ)|ψ⟩ — or, more generally, any unitary representing a change of admissible description), then ⟨ψ|A|ψ⟩ varies across observer descriptions and no fact ⟨A⟩_ψ is well-defined.

In each case, the structural argument is identical to §4.2: a function (whether M_D, the effect e, or the expectation map A ↦ ⟨ψ|A|ψ⟩) cannot return distinct values for the same input across admissible observers if its outputs are claimed as facts. The theorem is therefore not specific to function-based measurement — it constrains any framework in which "outcomes," "probabilities," or "expectation values" are claimed as observer-independent content.

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5. Failure Modes Without A0

Theorem 4.1 establishes the formal failure: no observer-independent measurement function exists for non-invariant distinctions. This section elaborates the failure across the three operational categories of physical theory — measurement, information, prediction — and addresses one apparent counterexample.

5.1 Collapse of measurement

By the necessity theorem, no measurement function M_D: 𝒮 → 𝒱 exists for an observer-dependent distinction D. Concretely: "measurement of D" yields different facts for different observers, and the apparatus has no unique result to register. Measurement loses operational meaning at the level of *which fact* it is registering.

5.2 Breakdown of information

Information theory grounds entropy in distinguishability. If distinguishability is itself observer-dependent and that dependence is treated as physical, then no observer-independent entropy function

$H: \mathcal{S} \to \mathbb{R}_{(\geq 0)}$

over the affected distinctions is well-defined. Channel capacity, mutual information, and the von Neumann entropy of mixed states all presuppose a definite distinguishability structure as input; without invariance under admissible observer change, that input is not a fact.

5.3 Loss of predictive laws

A predictive law specifies a function $F: \mathcal{S} \times \mathbb{R} \to \mathcal{S}$ from input states (and times) to output states. If "input state" and "output state" are observer-relative and that relativity is treated as physical, then **no observer-independent function $F: \mathcal{S} \to \mathcal{S}$ exists**. The theory contains one F per observer, with no fact about which is correct — i.e., no observer-independent law. Equivalently: *the state space ceases to support well-defined dynamics*, since dynamics requires inputs and outputs to be facts and there are no observer-independent facts to act on.

5.4 Note on relational interpretations

Sections 5.1–5.3 do not argue that *no* coherent physics can be built without A0. They argue that any physics that *does* take observer-dependent quantities to be physically real must give an alternative account of measurement, information, and prediction that does not collapse. This is a non-trivial constraint, not a refutation. We address relational interpretations directly in §7.

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6. A0 as a Separation Principle: Formalisation

The necessity theorem of §4 establishes that A0 is required. The present section gives the formal apparatus that makes A0 precise.

6.1 Equivalence classes

Let $\mathcal{O}$ be the set of admissible observer descriptions in the sense of §2.1. The relation

$x \sim y \iff O(x) = O(y)$ for every $O \in \mathcal{O}$

is an equivalence on the formal state space $\mathcal{S}$ of the theory, where O(x) denotes the representation of x under observer description O and equality between representations is understood as agreement on all commitment-event records.

The set of admissible observer transformations forms a group $\mathcal{G}$: composition of two admissible transformations is admissible (both preserve commitment-event records), each admissible transformation has an admissible inverse (relabellings are reversible), and the identity is admissible.

6.2 Statement (formal)

A0 (formal — also: the *Physical Content Invariance Principle*). *Physical content consists of equivalence classes under the group* $\mathcal{G}$ *of admissible observer transformations:*

$[x] = \{x' \in \mathcal{S} \mid g \cdot x = x' \text{ for some } g \in \mathcal{G}\}$.

Physical quantities are functions $f\colon \mathcal{S} \to \mathcal{V}$ *that descend to the quotient* $\mathcal{S}/\mathcal{G}$ *— that is, satisfy* $f(g \cdot x) = f(x)$ *for all* $g \in \mathcal{G}$ *and* $x \in \mathcal{S}$*.*

In this form, A0 is structurally identical to gauge invariance in modern physics: physical observables are $\mathcal{G}$-invariant functions on the formal state space. The difference is one of generality. Standard gauge invariance fixes $\mathcal{G}$ in advance for a given theory (e.g., U(1) for electromagnetism, Diff(M) for general relativity). A0 leaves $\mathcal{G}$ to be determined by the structure of admissible observers in the substrate, and asserts only that — whatever $\mathcal{G}$ turns out to be — physical content lives on $\mathcal{S}/\mathcal{G}$.

6.3 What A0 does

A0 specifies which quantities in a theory's formalism are eligible to be facts. It does not, by itself, determine which equivalence classes exist, what their structure is, or what dynamics relate them. Those require additional inputs — the substrate's structure, the theory's dynamical postulates, and the geometry of representation. A0 is the filter; the inputs supply what is filtered.

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7. Relation to Gauge Invariance and Relational Interpretations

Two clarifications matter for situating A0 in the existing landscape.

7.1 A0 vs. gauge invariance

Gauge invariance, in its modern form, refers to a redundancy of description: surplus mathematical structure that a formalism carries for technical reasons (locality, manifest symmetry, ease of quantisation). The gauge group acts on the formalism, and physical observables are required to be gauge-invariant.

A0 and gauge invariance are related but not identical:

- **Gauge invariance** is a property of *specific theories*: its content depends on what gauge group the theory carries. It is a tool internal to a chosen formalism.

- **A0** is a meta-principle: it states that, *whatever* equivalence among admissible observer descriptions a theory turns out to require, only invariants under it carry physical content.

Each instance of gauge invariance is therefore a specialisation of A0 to a particular structural setting. A0 is what gauge invariance is an example of, not a synonym for it. Diffeomorphism invariance in GR, U(1) in electromagnetism, and global-phase irrelevance in quantum mechanics are three distinct specialisations sharing the same underlying commitment.

This distinction matters because A0 generalises beyond contexts in which a gauge group is independently identifiable. In particular, the use of A0 in §9 below does not presuppose a gauge structure; it identifies one.

7.2 Relational interpretations

Quantum mechanical interpretations such as Rovelli's relational quantum mechanics (RQM) [3] and QBism [4] explicitly deny that *all* facts are observer-independent. RQM asserts that quantum events are facts relative to observers and that no single observer-independent state of affairs underlies them. QBism takes quantum probabilities as personal degrees of belief.

Are these counterexamples to A0? Not when A0 is read as a separation principle. The position they take is consistent with A0 if "observer-relative facts" in their sense correspond to commitment-event records relative to a particular observer's history of interactions, *and* the cross-observer consistency conditions they impose (e.g., RQM's stability requirement, QBism's coherence constraints) are themselves the invariants A0 isolates.

What A0 rules out is theories in which quantities vary across admissible observers without any invariant structure at all — i.e., theories with no inter-observer translation rules. RQM and QBism do not fall into this category; both impose substantial cross-observer consistency. The disagreement between them and a more conventional realist reading is about *what kind* of invariant structure underlies physics, not whether any does.

A0 is therefore compatible with relational interpretations under their actual commitments, while ruling out a stronger position — radical observer relativism — that those interpretations themselves do not endorse.

Compactly: *relational interpretations are compatible with A0 insofar as they supply invariant structures through cross-observer consistency conditions. A0 excludes only frameworks lacking any invariant layer.*

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8. From Implicit Assumption to Explicit Principle

Across modern physics, A0 is operative but unnamed:

- **Electromagnetism**: gauge potentials are not physical; field invariants are.

- **General relativity**: coordinate values are not physical; geometric invariants are.
- **Special relativity**: no preferred frame; only Lorentz-invariant intervals carry physical content.
- **Quantum mechanics**: global phase is unobservable; only inner products matter.
- **Statistical mechanics**: thermodynamic quantities depend on macrostates, not on representations of microstates.

Each of these is the projection of a specific equivalence onto its physical content. A0 is the meta-principle they all instantiate. Naming it is not idle: it lets us deploy the same projection in contexts where the relevant equivalence is not yet known and must be derived from the structure of the substrate.

8.1 A0 in the VERSF Programme

The role of A0 as a separation principle is not limited to abstract considerations. In the VERSF programme, it is deployed as a structural filter across distinct domains of physics, where it acts in conjunction with independent substrate-level premises to isolate the observed laws of nature from broader candidate structures.

Two companion developments illustrate this explicitly.

In the **relativistic sector**, A0 is applied to the question of inertial structure. When combined with auxiliary premises including finite signal propagation, homogeneity, isotropy, and the empirical absence of detectable substrate-frame effects, A0 eliminates all kinematic structures that depend on a physically resolvable preferred frame. The surviving transformation group is therefore Lorentzian rather than Galilean. In this setting, A0 functions as a gauge sieve: it does not generate spacetime structure, but removes any structure that would correspond to a substrate distinction observers cannot resolve through commitment-event records.

In the **quantum sector**, A0 operates in a different but structurally analogous way. When combined with the thermodynamic principle of fact formation (A1′) and the closure conditions on admissible representations, A0 eliminates non-relational pre-commitment structure. Any putative intrinsic properties of a system prior to irreversible commitment would either require physical encoding (and therefore entropy production) or would fail invariance under admissible observer transformations. The surviving structure is relational and is uniquely represented, under the closure conditions, by complex Hilbert space with Born-rule probabilities.

In both cases, the pattern is the same. A0 does not supply the underlying structure; it acts on a space of possibilities defined by auxiliary premises and removes those that fail invariance. What remains is uniquely constrained.

These results are developed in detail in the companion papers:

- *Distinguishability, Order, and Universality: A First-Principles Reduction of Relativistic Kinematics in VERSF* [1] (for the relativistic sector), and

- *Quantum Mechanics as the Representation Theory of Irreversible Commitment* [2] (for the quantum sector).

The present paper should therefore be read as providing the foundational principle that these derivations implicitly rely upon: a criterion for what counts as physical content, independent of the specific structures derived in each domain.

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9. A0 as a Projective Sieve

We now show A0 acting in concrete settings. In each subsection we identify, separately:

1. **Auxiliary premises** — what structural inputs are assumed.
2. **A0's contribution** — what non-invariant alternatives it eliminates.
3. **Surviving structure** — what is uniquely consistent with both.

The pattern is uniform: A0 does not generate; it projects. The surviving structure is not chosen, but it is forced *given the auxiliary premises*. Without those premises, A0 selects nothing.

Sections 9.1–9.4 follow this template. Section 9.5 makes a complementary necessity argument: that A0 is *already silently required* by general relativity and quantum mechanics as currently formulated. There A0 is not isolating structure from a candidate space; it is the unstated principle that lets the formal machinery of those theories carry physical interpretation at all.

9.1 Lorentz invariance over Galilean

Auxiliary premises:

- Spatial homogeneity and isotropy of the substrate.
- A finite invariant signalling speed (i.e., commitment events propagate at a finite maximum rate).
- Group closure of inertial transformations.
- **Undetectability of the preferred frame:** the substrate may carry a structural preferred frame F_0, but no admissible observer protocol resolves motion relative to F_0 through commitment-event records.

A0's contribution: Conditional on the undetectability premise, F_0-distinguishing quantities fail invariance under admissible observer change and are therefore not physical content. A0 thus eliminates the Galilean alternative — in which absolute simultaneity (a property tied to F_0) is treated as a fact.

In compact form:

The Galilean structure is admissible only if a preferred frame is physically detectable. In the absence of such detectability, A0 removes it, leaving Lorentz structure as the unique invariant group consistent with the auxiliary premises.

Surviving structure: Inertial transformations consistent with the four auxiliary premises and with A0 form the Lorentz group, by the Ignatowski-style derivation [5].

Honest accounting: The argument is therefore not "A0 → Lorentz" but "A0 + undetectability of F_0 + (homogeneity, isotropy, finite signal speed, group closure) → Lorentz." A0 alone does not pick out Lorentz invariance; the undetectability premise is essential, and is itself an empirical claim about the substrate. What A0 contributes, conditional on that empirical claim, is the elimination of the Galilean limit as a physical possibility.

9.2 Invariant causal order

This subsection delivers what A0 actually entails about temporal structure: *invariant causal order* on causally-connected pairs. The dimensionality of time is a separate question requiring additional structural inputs.

Auxiliary premises:

- Commitment events are irreversible.
- For each pair of commitment events, the substrate determines whether they are causally connected (one in the past lightcone of the other) or causally disconnected (spacelike-separated).

A0's contribution: For *causally connected* pairs, observer-dependent ordering would constitute a non-invariant fact about which event committed first. A0 forbids such facts. Causal order on causally-connected pairs must therefore be invariant across admissible observers.

Surviving structure: A partial order on commitment events whose restriction to causally-connected pairs is invariant. Causally-disconnected pairs may have observer-dependent labels for ordering, but no observer-dependent ordering is treated as a fact about which event preceded the other.

Honest accounting: This argument does not establish that time is one-dimensional. Special relativity already permits observer-dependent ordering of spacelike-separated events without inconsistency, and this is consistent with A0 under the present reading. The dimensionality of the temporal axis is a separate question requiring additional structural arguments (e.g., concerning the stability of dynamics under multiple time directions, the appearance of closed timelike curves, or the algebraic structure of commitment ordering). What A0 establishes here is narrower: invariant *causal* order, not one-dimensional time.

9.3 Universal gravitational coupling

Auxiliary premises:

- Gravitational interaction in the substrate ontology has a single source: committed-record density (or whatever the substrate's analogue is). No additional source-of-gravity property exists at the substrate level.
- Two configurations with identical substrate-level structure are, by hypothesis, identical at the level of all substrate quantities.

A0's contribution: A0 *reinforces* rather than derives universal coupling. The substrate premise — that committed-record density is the sole source of gravity — already entails that substrate-equivalent configurations gravitate identically; this is essentially a definitional consequence of the substrate ontology. A0's contribution is to seal off the loophole in which an additional, *undetectable*, composition-dependent coupling $\kappa_a \neq \kappa\_b$ could be smuggled in: such a coupling would generate non-invariant facts about substrate-equivalent configurations and is therefore eliminated.

Surviving structure: $\kappa_a = \kappa$ for all configurations — the weak equivalence principle.

Honest accounting: The substrate-level premise that committed-record density is the *sole* source of gravity does the primary structural work. WEP follows from that premise alone for cases where the coupling is in principle detectable; A0 extends the result to cases where the coupling would be undetectable in principle. In this sense A0 is corroborative, ruling out a possibility the substrate premise leaves formally open but cannot itself close.

9.4 Relational pre-commitment quantum structure

Auxiliary premises:

- **A1′ (thermodynamic fact formation):** No definite outcome exists prior to irreversible commitment. Any pre-commitment assignment of a definite value would constitute physical information without an entropy-producing event, violating the irreversibility–information link.
- The closure conditions developed in *Quantum Mechanics as the Representation Theory of Irreversible Commitment*, §3 — specifically, **compositional closure** (joint systems carry a consistent product structure) and **reversible pre-commitment dynamics** (evolution preserves distinguishability between commitments).

A0's contribution: Given A1′, pre-commitment configurations cannot carry intrinsic, observer-independent properties beyond their relations to other configurations: any non-relational distinction would either require physical encoding (a fact, prohibited by A1′) or fail invariance under admissible observers (prohibited by A0). What survives is exhausted by the relational distinguishability structure of pre-commitment configurations.

Surviving structure: In a representation space satisfying the closure conditions, the unique invariant encoding relational distinguishability structure is the modulus-squared inner product $|\langle\varphi|\psi\rangle|^2$.

The uniqueness has a clean statement:

Among all invariant encodings of relational distinguishability, the inner-product structure is uniquely compatible with compositional closure and reversible dynamics.

Equivalently, it is the only invariant that is simultaneously bilinear, positive-semidefinite, and additive across composite systems. The invariant is unique up to unitary equivalence (Theorem 7 of the companion paper): any two representations of the same relational distinguishability structure satisfying the closure conditions are related by a unitary transformation, so the choice of basis or phase convention carries no physical content. Via Theorems 4–6 of the companion paper, this structure leads to unitarity of pre-commitment evolution and the Born rule for commitment outcomes.

Honest accounting: This result is conditional on both A1′ and the closure conditions; it is not derived from A0 alone. A0's role is restricted to forbidding non-invariant distinctions; A1′ supplies the prohibition on pre-commitment definite values, and the closure conditions supply the geometric setting in which $|\langle\varphi|\psi\rangle|^2$ is the unique invariant. The result should be cited as an A0 + A1′ + (closure conditions) consequence, not as an A0 derivation.

9.5 Why GR and QM cannot function without A0

The four cases above show A0 isolating structure given auxiliary premises. We now make a complementary observation: A0 is not merely useful in stripped-down derivations but is *already silently required* by the two most successful physical theories we have. General relativity and quantum mechanics both depend on an A0-type separation between formal description and physical content. If that separation is removed, the formal machinery remains writable, but the theory no longer has well-defined physical interpretation.

Stated sharply: *the equations of GR and QM can be written without A0, but their physical interpretation requires it. Without quotienting by the relevant equivalence, the equations do not define unique physical states or predictions.* The necessity here is interpretive, not formal — and that is enough for physics, since a theory that cannot define unique physical states or predictions is not yet doing physics.

General relativity

General relativity is built on the distinction between coordinate description and geometric content. The same spacetime can be described using many coordinate systems. If coordinate-dependent quantities were treated as physical facts, then two observers using different coordinate charts could assign different "real" values to the same physical situation. The theory would then no longer describe invariant geometry; it would describe observer-dependent bookkeeping.

In GR, the metric components g_(μν) are by themselves coordinate-dependent. What carries physical content are diffeomorphism-invariant structures: intervals, curvature scalars, causal relations, geodesic relations, and tensorial equations expressed independently of coordinates. In standard GR language: *diffeomorphic metrics represent the same physical state*; this equivalence defines the quotient space of physical states in GR. Without an A0-type principle, this convention would lose its grounding — diffeomorphic descriptions would count as physically different worlds. General covariance would lose its physical meaning, and Einstein's equations would no longer specify a unique physical geometry but a family of coordinate-dependent descriptions.

GR therefore requires A0 in a precise sense:

Physical content of GR = diffeomorphism-invariant geometric content.

This is the formalisation of §6 applied to GR: physical quantities must descend to the quotient $\mathcal{S}/\mathcal{G}$ — here, the space of metrics modulo diffeomorphisms — rather than depend on the representative chosen in $\mathcal{S}$. Without that separation, GR collapses into coordinate convention.

Quantum mechanics

Quantum mechanics depends on the same separation. A quantum state vector $|\psi\rangle$ is not itself the full physical content: multiplying it by a global phase e^(iθ) changes the vector but not any physical prediction. If global phase were treated as physically real, then two mathematically equivalent descriptions of the same preparation would become distinct physical states despite producing identical measurement statistics.

Likewise, probabilities in QM depend on invariant relational quantities such as $|\langle\varphi|\psi\rangle|^2$, not on arbitrary representational features of the state vector. The companion paper *Quantum Mechanics as the Representation Theory of Irreversible Commitment* makes this explicit: pre-commitment quantum structure is relational, and the modulus-squared inner product is the invariant encoding of distinguishability under the closure conditions.

Without an A0-type principle, QM would suffer three concrete failures:

1. Global phase would become a physical fact despite being unmeasurable, introducing *non-empirical degrees of freedom* into the theory — formal distinctions that no observation can resolve. These correspond to elements of the representation space that do not descend to the quotient of physical states under the relevant equivalence (cf. §6.2).
2. Measurement probabilities would no longer be tied to invariant relational structure.
3. Physically equivalent state descriptions would generate different supposed "facts," breaking the link between state, measurement, and prediction.

QM therefore requires A0 in a precise sense:

Physical content of QM = observer/protocol-invariant relational content.

Combined result

GR and QM differ radically in their mathematics, but both require the same foundational move:

formal representation ≠ physical content.

GR needs this to separate geometry from coordinates. QM needs this to separate physical state content from phase and representation. Neither can function as a physical theory without an A0-type principle.

The stronger conclusion is therefore available:

A0 is not merely compatible with GR and QM — it is already silently required by both. GR is impossible as physics without diffeomorphism-invariant content; QM is impossible as physics without phase- and protocol-invariant relational content. A0 is the shared separation principle that makes both theories physically meaningful.

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10. Summary: What A0 Does and Does Not Do

The four cases above share a uniform mechanism. A0:

- Does **not** supply structural premises about the substrate, the dynamics, or the geometry.
- Does **not** generate physical structure ex nihilo.
- **Does** project the formalism of a theory onto its invariant content under the equivalence among admissible observer descriptions.
- **Does**, when combined with explicit auxiliary premises, eliminate non-invariant alternatives and thereby isolate a unique surviving structure.

The summary table:

Domain	Auxiliary premises	Eliminated by A0	Surviving structure
Spacetime	Homogeneity, isotropy, finite signal speed, group closure, undetectability of F_0	Preferred-frame distinguishability via observer protocol	Lorentz invariance
Causal order	Irreversibility of commitment, causal structure on events	Observer-dependent ordering of causally-connected pairs	Invariant causal order
Gravitation	Substrate-density as sole gravity source	Composition-dependent coupling	Weak equivalence principle
Quantum (pre-commitment)	A1′, compositional closure, reversible dynamics	Non-relational pre-commitment properties	Relational Hilbert-space structure; Born rule

Each row is a *joint* result, not a derivation from A0 alone. The framing throughout is deliberate: A0 is a sieve, and the structures it isolates are forced only relative to the auxiliary premises in the corresponding row.

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11. Conclusion

Observer-invariant distinguishability is best read not as a stand-alone axiom, nor as a generator of physical structure, but as a *separation principle* that partitions the apparatus of a physical theory into representational surplus and physical content. So read, it is:

- **necessary** — the theorem of §4 establishes that any theory violating A0 cannot define measurement, information, or predictive law as facts; §9.5 shows this necessity already operative within general relativity and quantum mechanics, both of which require an A0-type separation between formal representation and physical content to function as physics at all;
- **formal** — A0 is statable as the requirement that physical quantities descend to the quotient $\mathcal{S}/\mathcal{G}$ under the group of admissible observer transformations, with the same structural form as gauge invariance in modern physics;
- **compatible with relational interpretations** under their actual commitments;
- **distinct from but generalising** each instance of gauge invariance;
- **operative** across spacetime, causal, gravitational, and quantum settings.

When deployed as a projective sieve — combined with explicit auxiliary premises about the substrate, dynamics, and representation — A0 isolates familiar structures of physics from broader candidate spaces. In each case the auxiliary premises do the structural work; A0 does the eliminative work. Both contributions are necessary; neither is sufficient.

The principle is therefore neither trivial nor omnipotent. It is what physics has always been quietly doing: identifying what remains when all admissible descriptions agree, and treating only that as the subject of inquiry.

The results of the VERSF programme suggest that observer-invariant distinguishability is not merely a consistency condition on physical theories, but a principle that actively constrains their form. Any theory lacking shared empirical content fails to meet the minimal criterion for a physical theory: that its predictions can be tested intersubjectively. Whether A0 is fundamental remains open; that it is unavoidable for any theory with observer-independent content does not.

Without A0, the distinction between physics and description collapses.

A theory without A0 cannot distinguish between physically different worlds.

12. Anticipated Questions and Objections

The paper has been developed through multiple rounds of referee-style critique. The questions below address the concerns most likely to arise from readers approaching A0 from different traditions — formal foundations, philosophy of physics, and working physics. Answers are deliberately compact; section references point to the fuller treatment in the body.

Q1. Doesn't A0 rule out relational interpretations like RQM and QBism?

No. A0 rules out *radical observer relativism* — the position that no invariant structure underlies physics at all. RQM and QBism both impose substantial cross-observer consistency conditions (RQM's stability requirement, QBism's coherence constraints), and those conditions are precisely the invariants A0 isolates. A0 is therefore compatible with relational readings under their actual commitments; it excludes only positions those interpretations themselves do not endorse. (See §7.2.)

Q2. Is A0 a metaphysical claim or a structural one?

Structural. A0 does not claim that observer-independent reality exists in any metaphysically loaded sense. It claims that any theory making observer-independent predictions — *if* such predictions are to be well-defined — must restrict its physical content to invariants under the equivalence among admissible observers. The structural reading is compatible with anti-realist and relational positions; it is incompatible only with positions that posit observer-dependent facts as physically real while still claiming to do physics. Whether observer-independent reality "actually exists" in some deeper metaphysical sense is a separate question A0 does not adjudicate.

Q3. How is A0 different from gauge invariance?

Gauge invariance is a property of *specific theories* whose gauge group is independently identified for technical reasons (locality, manifest symmetry, ease of quantisation). A0 is a meta-principle: it states that whatever equivalence among admissible observer descriptions a theory turns out to require, only invariants under that equivalence carry physical content. Each instance of gauge invariance is a specialisation of A0; A0 is what gauge invariance is an example of, not a synonym for it. (See §§6.2 and 7.1.)

Q4. Isn't the definition of admissible observers circular?

No. Admissibility is defined via structure-preserving transformations on commitment-event records, not via agreement on values. The equivalence relation is specified prior to, and independently of, the notion of facthood. A0 then says physical content lives on the quotient — this conclusion is reached *from* a non-circular definition, not built into it. (See §2.2.)

Q5. Do GR and QM actually require A0, or do they just happen to satisfy it?

Require. The equations of GR and QM can be written down without invoking A0, but they cannot be physically interpreted without it. Without quotienting metric components by diffeomorphisms, GR's equations specify a family of coordinate-dependent descriptions rather than a unique geometry. Without quotienting state vectors by phase, QM's predictions become ill-defined — global phase becomes a non-empirical degree of freedom. The necessity is interpretive, not formal, and that is enough: a theory that cannot define unique physical states or predictions is not yet doing physics. (See §9.5.)

Q6. Does the necessity theorem rest on a particular notion of measurement?

No. The theorem was stated for measurement functions M_D: $\mathcal{S} \to \mathcal{V}$, but the structural argument extends uniformly to generalised probabilistic theories (effects e acting on states ω) and to operator-based formulations (observables A with expectation values $\langle\psi|A|\psi\rangle$). In each case the failure mode is the same: a function cannot return distinct values for the same input across admissible observers if its outputs are claimed as facts. (See §4.4.)

Q7. If A0 doesn't generate physics by itself, what does it add?

A filter. Given a candidate space of structures specified by auxiliary premises (substrate ontology, dynamics, representation), A0 eliminates non-invariant alternatives. The structures of physics — Lorentz invariance, the weak equivalence principle, complex Hilbert space — emerge from the joint application of A0 and substrate-level premises. Neither A0 nor the premises alone is sufficient; both are necessary. The contribution of A0 is eliminative; the contribution of the premises is constructive; both are required to isolate a unique structure. (See §§9.1–9.4.)

Q8. Is A0 falsifiable?

Indirectly. A0 itself is a structural requirement on what counts as physical content; it is not directly falsified by experiment. The *premises* on which A0 acts are empirical and falsifiable. If a preferred substrate frame turned out to be detectable, A0 would no longer eliminate Galilean structure. If a non-relational pre-commitment property turned out to be measurable, A0 would no longer mandate relational quantum structure. The empirical content of A0's applications therefore lies in the auxiliary premises, which are themselves falsifiable; A0 supplies the structural reasoning that converts those empirical facts into eliminations of candidate theories.

Q9. What about theories that posit observer-dependent facts as fundamental — could one still call this physics?

Such theories may be coherent as formal systems, but they cannot deliver shared empirical predictions across observers, by the theorem of §4. They therefore fail to satisfy what a physical theory is conventionally required to do: produce predictions whose verification is not itself observer-dependent. A0 marks the dividing line. Below that line lie observer-relative formal systems; above it lie theories of observer-independent physical facts. The paper claims only that the latter requires A0, not that the former is incoherent in some absolute sense.

Q10. Why the label "A0"?

The label reflects status: A0 is a precondition for the axioms a physical theory typically posits. Most foundational programmes begin with axioms about specific structures (the principle of relativity, the superposition principle, gauge symmetry of a particular group). A0 sits underneath these, specifying what counts as physical content before any specific structural claim is made. The numbering acknowledges that A0 is logically prior to the axioms of any particular theory, while remaining one ingredient among several when specific structures are derived.

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