Substrate Cosmology Volume Five

Measurement, Detectors, and Experimental Interaction

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This book presents a developing research program. Substrate Cosmology and Fibered Relational Tensor Theory are not established physical theories. No experiment described here has confirmed a new physical invariant, an alternate dimension, nonrelativistic influence, inertial modification, gravitational control, localization transfer, or any departure from established physics. The photonic and cold-atom systems discussed are first of all known-physics benchmarks in which state preparation, coupling, measurement, and information loss can be made unusually explicit.

The proposed experiments are research designs, not instructions to bypass laboratory competence, laser safety, electrical safety, cryogenic or vacuum procedures, institutional review, export controls, or applicable law. Qualified laboratories must produce their own engineering drawings, hazard analyses, standard operating procedures, uncertainty budgets, and approvals.

Authorship and AI Collaboration

James Dunn originated Substrate Cosmology, the distinction between Actual Physics and represented physics, the Relational Tools, the Fibered Relational Tensor Theory program, and the requirement that an embedded observer's limitations not be promoted into limits on physics. He supplied the research corpus, apparatus proposals, corrections, continuity records, and public website from which this volume was developed. He retains responsibility for the claims and publication.

OpenAI ChatGPT (Codex) reviewed the available corpus and website, reconstructed the experimental dependencies, compared the proposed apparatus with metrological and reproducibility requirements, distinguished known-physics benchmarks from candidate extensions, drafted and edited the text, prepared protocols and audit forms, produced the document, and integrated it with the public research commons.

Microsoft Copilot and Google Gemini are acknowledged for earlier assistance recorded in the source manuscripts. AI systems are cited as collaborators in representation, analysis, and production. They are not empirical witnesses, independent replicators, scientific authorities, or evidence that a physical claim is true.

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Contents

Preface

The previous volumes prepared a researcher to notice a persistent error: a successful representation is allowed to become the thing represented. Volume One separated Actual Physics from observer-accessible physics. Volume Two showed how words, numbers, units, coordinates, and equations conceal their selections. Volume Three organized the Relational Tools for retaining distinctions and auditing loss. Volume Four proposed a mathematical architecture in which regimes, fibers, translations, projections, and recovery maps could be named without pretending that the architecture was already a theory of nature.

Volume Five brings that discipline to the laboratory. It begins from a fact that is obvious in engineering and still easy to forget in interpretation: an instrument is a physical system. It prepares, couples, filters, amplifies, saturates, samples, transforms, stores, and reports. A detector never receives “everything that is there.” It participates in one chain of interaction and produces a record within a chosen representational lexicon.

This does not make measurement arbitrary. Quite the opposite. Once the detector is admitted into the physics, objectivity becomes more demanding and more concrete. The preparation must be specified. The interaction must be modeled. The detector transfer function must be calibrated. Environmental couplings must be monitored. Independent projections must be genuinely independent. A null result must be interpretable. A positive result must survive leakage tests and conventional explanations.

The hardest conceptual redirections in the research are therefore used as the order of presentation. Proposed relations repeatedly collapsed back into scalars. Proposed dimensions became extra spatial axes. Recurrence became periodic motion. Precausal ordering became retrocausality. Relativity became both the recovered predictive structure and the assumed container of every possible ontology. A detector reading became a property possessed by the system without qualification. Each collapse removed the very distinction the project meant to study.

The experimental program corrects the order. It starts with ordinary platforms whose physics is well understood, asks whether multiple physical organizations can be deliberately prepared under a declared measurement equivalence, and then applies a preregistered operation that may respond differently. The first outcome may be entirely conventional. Indeed, that is the desired first benchmark: learn to expose relational distinguishability without mistaking it for new physics. Only after the method survives known-physics tests, independent detection, blind analysis, and cross-platform replication may stronger candidates be entertained.

The Current Series

The series has no predetermined length. Volumes may divide, combine, or change order as conceptual dependencies, formal results, or evidence require.

Volume	Working title	Primary task
One	Introduction to Substrate Cosmology	Establish the alternate perspective and research boundaries.
Two	Words Units and the Collapse of Physical Representation	Make linguistic, numerical, metrological, and mathematical selection inspectable.

Volume	Working title	Primary task
Three	The Relational Tools and Their Developmental Lineages	Preserve, explain, crosswalk, and operationalize the Tool architecture.
Four	Relational Mathematics and Fibered Relational Tensor Theory	Develop formal objects, projections, recovery maps, and conservative extension.
Five	Measurement Detectors and Experimental Interaction	Model apparatus, controls, independent projections, and discriminating interventions.
Six	Recurrence Research and the Labyrinth	Develop recurrence methods, blind archives, null worlds, and prospective validation.
Seven	Cosmology Matter and Emergent Physical Quantities	Reconsider spacetime, matter, fields, gravity, energy, entropy, horizons, and dark phenomena.
Eight	Conditional Engineering and Physical Manipulation	Examine intervention and engineering only under explicit evidence and safety gates.
Nine	Intelligence Agency Identity and Dimensional Stewardship	Develop relational learning, culture, ethics, AI, and propagation of diverse life.
Ten	Substrate Cosmology Website User Manual	Document the research commons, investigation routes, evidence boundaries, and continuity controls.

Volume Six will receive experimental records from this volume, including the null worlds and blind archives needed for recurrence research. Volume Ten remains the dedicated website manual; Chapter Forty Eight in this volume is the apparatus-program user’s guide for the website, not a substitute for that manual.

Acknowledgments

This volume grows from James Dunn's insistence that the limitations of an embedded observer are not automatically limitations of physics. His corrections repeatedly forced the research away from an easy return to familiar containers and toward a sharper question: which distinctions are physical, which are representational, which are created by the interrogation, and which are erased by the report?

OpenAI ChatGPT (Codex) is acknowledged for corpus review, experimental dependency reconstruction, metrological and statistical criticism, manuscript development, document production, and website integration. Microsoft Copilot and Google Gemini are acknowledged for earlier recorded assistance. Their work is provenance, not confirmation.

The experimental discipline used here also depends on the long work of metrology, experimental design, operational quantum theory, causal inference, synthetic-dimension research, reproducibility reform, and open-data practice. Those communities do not endorse Substrate Cosmology by being cited. Their methods are constraints the program must satisfy.

Reader Guide

Status Labels

Label	Meaning
Established interface	Accepted theory, method, or instrument behavior used within a declared domain.
Known-physics benchmark	A test expected to be explained by established physics, used to validate the method.
Project definition	A stipulated term used by Substrate Cosmology.
Candidate observable	A proposed quantity whose operational definition is incomplete or unvalidated.
Confirmatory test	A preregistered test with fixed candidate, controls, exclusions, and analysis.
Exploratory test	A search that may generate hypotheses but cannot confirm the discovered one on the same data.
Empirical anomaly	A replicated departure from a sufficiently complete baseline; not yet new physics.
Open problem	A missing model, calibration, proof, control, or result blocking stronger claims.

The Evidence Discipline

The reader should keep three statements separate:

1. Two preparations are equivalent under specified measurements within stated tolerances.
2. A later intervention distinguishes them.
3. The distinction requires an extension of established physics.

The first two can occur within ordinary physics. The third requires exhaustive model comparison, artifact control, replication, and theoretical closure. This volume is mainly about learning to do the first two well enough that the third can eventually be asked without confusion.

Reading Paths

Experimental physicists should read Parts I through III, then the candidate experiment matching their platform and the appendices. Metrologists and statisticians should begin with Chapters Five, Six, Ten, Thirty Seven through Forty Four, and Appendices A through F. FRTT researchers should read Chapters Seven through Fifteen and Twenty Five through Thirty Eight. Website participants should read Chapter Forty Eight before contributing a proposed experiment or result.

Introduction

Measurement From Inside the Environment

Physics is investigated by physical systems inside physics. The laser, cable, resonator, clock, observer, software process, memory device, and unit convention are not outside the world as neutral windows. They are parts of a coupled event. That statement does not weaken experimental knowledge. It identifies the conditions under which experimental knowledge is possible.

Let an unknown physical condition be represented provisionally by s. A useful measurement chain is

$$s \xrightarrow{P} s_P \xrightarrow{U} s_U \xrightarrow{C} x \xrightarrow{D} y \xrightarrow{K} d \xrightarrow{A} r\,.$$

Here P is preparation, U the experimental intervention, C the coupling into an instrument, D transduction, K calibration and digitization, d retained data, A analysis, and r the reported result. Every arrow is physical, mathematical, or both. Every arrow may preserve some distinctions, merge others, and introduce dependencies.

The report r is not false because it is downstream. It is conditional. The danger begins when downstream equivalence is moved upstream without argument: two equal numbers are declared to be one physical state; a unit is allowed to define the ontology of its quantity; a spatial plot is treated as proof that a relation is spatial; or a clock label is treated as time itself.

The Experimental Question

The central experimental pattern in this volume is:

$$P_{std}(s_1) \approx P_{std}(s_2),\, \alpha(s_1) \neq \alpha(s_2),$$

followed by a common operation U_α and an ordinary observation:

$$O_{std}(U_\alpha s_1) \not\approx O_{std}(U_\alpha s_2).$$

P_{std} is not "everything mainstream physics can know." It is the declared verification bank used to establish operational equivalence for a particular experiment. The candidate α names the retained difference believed to matter to the intervention. If preparation history, phase correlations, hidden modes, thermal structure, or control electronics predict the outcome, they belong in the standard model. They may not be excluded merely to manufacture mystery.

The first demonstrations of this pattern should use synthetic dimensions and other controllable known-physics systems. They teach the research program how measurement equivalence can conceal physical organization. They do not show that nature contains a new dimension or that FRTT is correct.

The Redirections That Shaped This Volume

The research repeatedly needed to be redirected at six boundaries:

Drift	What was lost	Experimental correction
Relation became scalar	Internal structure and context	retain structured state and projection metadata
Dimension became axis	operational mode became geometry	declare how adjacency is enacted, not merely plotted
Recurrence became vibration	return structure became periodic motion	record recurrence relations without assuming a clock waveform
Precausality became retrocausality	ordering before spacetime became backward time	avoid causal language until operational order is defined
Relativity became container	recovered interface became exclusive ontology	require relativistic recovery while testing richer models conservatively
Detector reading became property	interaction chain disappeared	model preparation, coupling, transduction, calibration, and report separately

The chapters follow these corrections. Their purpose is not to persuade a reader to “believe” an unseen substrate. Their purpose is to build enough alternate perspective that the reader can design comparisons which do not decide the answer through their own vocabulary.

Part I

What Measurement Is

Chapter One

The Apparatus Is Inside Physics

An apparatus is an organized physical participant. Even a nominally passive sensor exchanges momentum, energy, phase information, charge, heat, or correlations with the measured system. The physical meaning of a reading therefore depends on a coupling model. A photodiode current, a heterodyne spectrum, a calorimetric temperature rise, and a photon-counting record can all originate from the same optical field while retaining different distinctions.

Substrate Cosmology calls the unknown target *Actual Physics* to prevent a model from becoming identical with its target. The term does not designate a hidden substance. It marks epistemic discipline. An experiment constrains Actual Physics through reproducible relations among physical preparations and records; it does not step outside physics to compare a representation with reality directly.

This viewpoint changes the meaning of a detector limitation. A bandwidth limit is not a declaration that faster structure does not exist. A spatial aperture is not proof that excluded modes are unreal. A unit choice is not proof that the measured relation possesses only the dimensions shown in the unit. The limitation belongs first to the interaction and representation. Whether it also marks a physical absence is a further inference.

The practical rule is simple: every claimed property must be accompanied by the path that made it observable. “The state has frequency f” is replaced by “under preparation P, coupling C, reference clock q, estimator A, and calibration K, the record supports frequency f with uncertainty u_f.” The longer statement is not pedantry. It prevents the unit from concealing the event that produced it.

Chapter Two

Preparation Interaction Projection and Report

Four layers must be recorded even when ordinary laboratory shorthand combines them.

Layer	Function	Common collapse
Preparation	establishes a reproducible physical condition	treated as a label rather than an operation
Interaction	changes or couples the prepared condition	called “measurement” without a transfer model
Projection	selects what the apparatus makes distinguishable	treated as the whole state
Report	encodes a result in values, units, and language	treated as direct possession by nature

A preparation recipe is not a state description unless its relevant contingencies are controlled. Two devices set to the same nominal voltage may have different thermal histories. Two optical fields with the same power spectrum may have different phase relations. Two atomic ensembles with the same populations may have different coherences. The preparation record must include all variables capable of predicting the outcome under the best available model.

A projection is not necessarily mathematical projection in a narrow linear-algebraic sense. It is any many-to-one availability relation induced by the apparatus and analysis. A binning rule projects arrival times. A power meter projects a field into absorbed energy over an interval. A spectrum analyzer projects temporal structure through resolution bandwidth, windowing, and detection electronics. The report adds another projection through rounding, units, plots, and prose.

FRTT uses this chain to ask whether the same physical organization admits several local descriptions and whether translations between them preserve the relations needed by an intervention. Volume Four expressed that question through fibers and recovery maps. Volume Five asks what hardware and records would make it testable.

Chapter Three

Observation Is Not Passive

The phrase “observer effect” is too broad to do experimental work. What matters is a specified disturbance or coupling. In classical measurement, loading, heating, back-action, quantization, hysteresis, and finite response can alter the target. In quantum measurement, the allowed outcomes and state update depend on the measurement operation. In both cases, “observation” is a physical process, not a disembodied act of awareness.

Three interactions should be separated:

- preparation back-action: controls change more than the intended degree of freedom;
- interrogation back-action: the probe changes the evolving state;
- registration back-action: transduction and amplification alter or destroy the carrier while creating a durable record.

The experimental design should identify which effects are modeled, monitored, randomized, or made common mode. If a proposed relational distinction can be inferred from the control waveform, cable temperature, software branch, or acquisition timing, a later detector difference does not test hidden relational organization. It tests leakage.

The deeper lesson is that access is enacted. A relation becomes experimentally available because an apparatus couples to it. This is why “what you see is what exists” is insufficient: sight itself is an interaction architecture. Scientific realism is strengthened when the architecture is made explicit.

Chapter Four

Detector-Induced Equivalence Classes

For a detector-and-analysis system M, define

$$s_1 \sim_M s_2 \text{ when } d\left(p_M(\cdot \mid s_1), p_M(\cdot \mid s_2)\right) \le \varepsilon_M ,$$

where p_M is the distribution of possible records, d a declared statistical distance, and ε_M a tolerance justified before examining the confirmatory result. This is an operational equivalence, not identity.

Different detectors produce different equivalence classes. A total-power meter can merge fields separated by phase structure. A spectrum analyzer can merge time order. A threshold detector can merge amplitudes above saturation. A calibrated heterodyne receiver may separate some distinctions while introducing dependence on its local oscillator and clock.

The set of systems indistinguishable to one detector is therefore not evidence that the systems are physically identical. Nor does distinguishability by another detector automatically reveal a deeper ontology. It shows that the two measurement interactions partition the state space differently.

The first experimental objective is to construct and verify such differences deliberately. If the program cannot do this in systems where the hidden organization is known by design, it is not ready to search for unknown relational variables.

Chapter Five

Calibration Traceability and Uncertainty

Calibration relates an instrument response to reference procedures and standards. Traceability supplies a documented chain of comparisons, each with uncertainty. Neither makes an instrument infallible. Together they make claims transportable across instruments, laboratories, and time.

An uncertainty statement is not an admission that nothing is known. It describes dispersion assigned to the measurand under a model. The measurand itself must be defined: optical power averaged over which interval, at which plane, over which bandwidth, under which polarization, after which correction? A number without this definition is a label detached from its interaction.

Volume Two argued that units conceal selections. Metrology makes those selections visible. A watt is extraordinarily useful, but equal average power does not imply equal modal organization, phase relation, temporal sequence, entropy, or coupling susceptibility. The correct conclusion is not that the watt is deficient. It is that every unit answers a specified question.

Each protocol in this volume therefore requires an uncertainty budget containing calibration uncertainty, repeatability, drift, digitization, model correction, environmental sensitivity, and sampling uncertainty. Correlations among components must be recorded. The final comparison must propagate uncertainty through the actual analysis, not append an error bar as decoration.

Chapter Six

Identifiability and Operational Equivalence

A parameter is identifiable when distinct parameter values imply distinguishable distributions of observable data under the model and design. A relational candidate that can change while every permitted observation remains unchanged is not empirically identified. It may be a useful formal redundancy, but it has no demonstrated physical leverage.

Non-identifiability also arises when candidate and nuisance effects make the same prediction. If detector nonlinearity, thermal drift, and candidate adjacency all produce the same output change, the experiment has not isolated adjacency. Additional interventions or independent projections are needed to rotate those explanations apart.

Operational equivalence must be demonstrated with equivalence testing or another explicit bound. Failure to reject a difference is not proof of sameness. The experiment must state how large a mismatch would matter, acquire enough information to exclude mismatches larger than that tolerance, and include calibration uncertainty in the decision.

This creates a productive tension. Preparations must be equivalent enough that ordinary differences cannot explain the result, yet distinct enough in the candidate relation that the intervention has power. The design problem is not to hide a difference. It is to localize it.

Part II

Designing the Comparison

Chapter Seven

The Decisive FRTT Criterion

The proposed decisive pattern is:

$$P_{std}(s_1) \equiv_{\varepsilon} P_{std}(s_2), \alpha(s_1) \neq \alpha(s_2),$$

and, for a common preregistered intervention U_{α},

$$O_{std}(U_{\alpha} s_1) \not\equiv_{\delta} O_{std}(U_{\alpha} s_2).$$

The subscript “std” names the strongest relevant established model and verification bank available to the experiment, not a deliberately impoverished list of scalars. If ordinary theory predicts the outcome from preparation provenance, then the experiment is a known-physics demonstration. That can still be valuable: it validates the measurement-equivalence method.

A result becomes interesting for FRTT only when a candidate relational descriptor improves prospective prediction across interventions and platforms without being a renamed conventional variable. A result becomes evidence for new physics only after the established model class, apparatus effects, and information leakage have been seriously exhausted. These are different thresholds.

The criterion is deliberately reversible. A candidate α that never changes predictive distributions after exhaustive sensitive interventions has no demonstrated empirical leverage. It may be removed, redefined, or retained only as bookkeeping. The program does not protect a candidate from null evidence.

Chapter Eight

Candidate Freeze and the Minimal Carrier

Before apparatus construction, the candidate must be frozen in an operational record:

$$\alpha = (C, X, R, O, \Pi, M, \Gamma).$$

C is context, X the carrier, R retained relations, O permitted operations, Π declared projections, M measurement channels, and Γ provenance and uncertainty. This tuple does not claim ontology. It prevents the candidate from changing meaning after results appear.

The minimal carrier is the least physical system on which the proposed distinction can be enacted and read. For adjacency multiplicity it may be a set of optical frequency modes plus programmed couplings. For recurrence it may be a sequence with a defined return relation. For cross-frame comparison it may be one preparation interrogated by two independently calibrated measurement architectures.

Freeze documents should also state what would count as the same candidate across platforms. If photonic adjacency and cold-atom adjacency share only a metaphor, cross-platform agreement is not replication. The invariant mapping must be specified before results are compared.

Chapter Nine

The Mainstream Baseline

The baseline is an adversary in the constructive sense: it must be allowed to explain as much as established physics legitimately can. Optical models may include full complex fields, phase noise, mode coupling, dispersion, nonlinear response, loss, detector response, thermal effects, and control histories. Atomic models may include interactions, trap inhomogeneity, decoherence, state preparation, detection fidelity, and control noise.

The baseline must be versioned and closed before confirmatory unblinding. Model components may not be added selectively to absorb one arm while ignored in another. Conversely, an unexplained residual may not be promoted to new physics merely because the initial baseline was simple.

A useful baseline hierarchy is:

Tier	Purpose
B0	direct empirical calibration and conservation checks
B1	standard linear device model
B2	known nonlinearities and environmental dependencies
B3	full preparation and control provenance
B4	competing segmentation and alternative ordinary mechanisms

The confirmatory question should be tested against the highest tier justified by available knowledge. Earlier tiers are diagnostic, not rhetorical targets.

Chapter Ten

Measurement Chains and Nuisance Models

Every channel receives a measurement-chain diagram from physical input to reported statistic. The diagram names sensors, amplifiers, filters, clocks, digitizers, firmware, file formats, corrections, exclusions, and software versions. It also identifies where saturation, aliasing, clipping, dead time, drift, rounding, and human judgment can enter.

A nuisance variable is not irrelevant. It is a variable whose influence must be controlled or marginalized to estimate the target effect. Environmental temperature, polarization, laser detuning, RF phase, cable delay, detector gain, and analysis window can all mimic relational sensitivity.

The nuisance model should distinguish common-cause variables from mediators. Correcting for a mediator can remove the effect one intends to study; failing to control a common cause can create a false effect. The causal diagram belongs in the preregistration.

When a nuisance cannot be measured reliably, the design should randomize or balance it, introduce a reference channel, or narrow the claim. An unmeasured nuisance does not disappear because the protocol lacks a field for it.

Chapter Eleven

Controls Shams and Signal Injection

A strong experiment contains several kinds of control:

- a positive control that demonstrates sensitivity to a known distinction;
- a negative control expected to remain equivalent;
- a sham intervention that reproduces switching, timing, and software without the target coupling;
- a reference path that experiences environmental conditions but not the candidate operation;
- a signal injection that tests recovery of a hidden known effect through the entire pipeline.

Signal injection should occur at more than one level. Hardware injection verifies the physical chain. Digitizer-level injection verifies acquisition and storage. Analysis-level injection verifies estimation. These tests must not leak the confirmatory allocation.

Sham trials are particularly important when the apparatus is reconfigured. Relay switching, RF loading, thermal settling, or code-path differences can identify the arm. The sham must reproduce these side effects while withholding the candidate relation.

Chapter Twelve

Randomization Blinding and Preregistration

Randomization protects against time-correlated drift when allocation is concealed and implemented correctly. Blocked or stratified randomization may be required when devices have long settling times. The seed, generator, block scheme, exclusions, and emergency unblinding process must be recorded.

Blinding should extend to the extent physically possible: operators need not know which compiled waveform represents which candidate; analysts can receive labels with a held key; replication sites can exchange preparations and analysis containers without sharing expected direction. Instrument automation is not itself blinding if filenames or waveforms reveal allocation.

Preregistration freezes the question, primary outcome, equivalence margins, exclusion rules, sample size, statistical model, multiplicity correction, and claim threshold. Exploration remains welcome, but exploratory results must be labeled and tested on new data.

The blind key is a physical and informational object. Its creation, custody, checksum, authorized access, and release time belong in the provenance record.

Chapter Thirteen

Independent Projections

Two instruments are not independent merely because there are two of them. Identical detectors can share a blind spot, calibration source, clock, software library, or physical transduction. Independence is graded.

Independence dimension	Example question
Transduction	do the channels convert the carrier by different physics?
Reference	do they depend on the same local oscillator or standard?
Clock	can one timing fault move both results?
Environment	are they co-located or separately shielded?
Software	do they share parsing, filtering, or fitting code?
Team	can expectation or undocumented practice propagate?

Agreement across independent projections increases confidence that a result is not a channel-specific artifact. Disagreement is information, not failure to be hidden. It can identify which distinctions each apparatus retains.

No number of detector agreements proves ontology. The claim remains about invariance across tested interactions.

Chapter Fourteen

The Resource Ledger

An intervention can appear anomalous when an uncounted resource carries the distinction. The resource ledger records energy, momentum, angular momentum, charge, particle number where applicable, entropy export, coherence consumption, reference frames, phase standards, clock synchronization, control information, memory, bandwidth, and computation.

Information is not added as a mystical substance. The ledger asks which physical systems store and transmit distinctions. A waveform generator, lookup table, feedback controller, and local oscillator can all supply structure to an experiment. If two arms require different control resources, that difference may explain later behavior.

The ledger must specify boundaries. Energy conserved inside the optical subsystem may not be conserved if RF drives and thermal reservoirs are excluded. A claim of “no energy input” is meaningless until the accounting surface and interval are named.

Resource closure is therefore a gate before strong interpretation. Unexplained residuals in the ledger trigger investigation, not metaphysical promotion.

Chapter Fifteen

Provenance and Analysis Freeze

Raw data are not simply the first convenient file. They are the earliest retained records from each channel, accompanied by calibration, configuration, timing, and integrity metadata. When on-device processing cannot be bypassed, that processing becomes part of the measurement chain and must be versioned.

The archive should preserve immutable raw objects, checksums, a machine-readable manifest, calibration snapshots, control waveforms, environmental logs, software environments, and the blind-key commitment. Derived data must point back to inputs and transformation code.

An analysis freeze is a tagged, executable version of the pipeline produced before unblinding. Containerization helps but is not sufficient; proprietary firmware, external references, and random seeds must also be documented. The result package should allow an independent team to regenerate tables and figures from retained inputs.

Part III

Apparatus Architecture

Chapter Sixteen

The Synthetic-Frequency Benchmark

The recommended first platform is a photonic synthetic-frequency-dimension system. Optical frequency modes form a controllable set of sites; electro-optic modulation creates couplings among them; phase and amplitude programming alter effective adjacency. Synthetic dimensions are established laboratory constructions. Their value here is methodological: relations that would be difficult to rearrange in ordinary space can be programmed, measured, and modeled.

The phrase “synthetic dimension” must not be allowed to prove an ontological extra dimension. It names an effective lattice coordinate constructed from accessible modes and couplings. The experiment asks how different relational organizations survive selected projections and respond to later operations.

The first apparatus should be deliberately modular. Generation, preparation, verification, candidate operation, independent detection, environment, and control should have distinct interfaces. A monolithic setup can produce excellent physics but makes causal auditing harder.

Chapter Seventeen

State Generation

The generation module may include a narrow-linewidth tunable continuous-wave laser, an independent reference laser, an optical frequency comb, locking electronics, polarization control, attenuation, and optical isolation. Each component adds both capability and possible leakage.

A fiber-ring resonator offers an accessible first synthetic-frequency lattice. Electro-optic phase and amplitude modulators driven by phase-coherent RF sources create intermode couplings. An arbitrary waveform generator programs the coupling graph. An acousto-optic modulator can gate trials or shift frequency. A pulse shaper provides spectral amplitude and phase control.

The generation record should retain the compiled waveform, source code, requested graph, measured RF output, optical input spectrum, lock status, polarization, and thermal state. The compiled waveform must not contain an unnecessary signature of the experimental arm.

Later implementations may use integrated electro-optic resonators, coupled resonators, or boundary-engineered networks. These are upgrades after the modular fiber system establishes the measurement discipline.

Chapter Eighteen

The Standard Projection Bank

Before the discriminating operation, the two preparations are compared under a declared bank. A serious bank may include total optical power, mean frequency, resolved spectrum, selected complex transfer-function points, polarization, temporal envelope, heterodyne phase statistics, and environmental state.

Matching one spectrum trace is insufficient. Analyzer resolution, sweep time, window, dynamic range, and reference stability determine what the trace can exclude. Equivalence margins must be derived from the predicted sensitivity of the later operation.

The verification bank should contain at least one channel capable of exposing each known conventional distinction that could drive the primary outcome. When this is impossible, the unmeasured distinction enters the nuisance model and limits the claim.

Chapter Nineteen

The Second-Stage Operation

The two verified preparations enter the same second-stage operation. This may be a second modulated resonator, a programmable coupling network, a pulse-shaper transformation, or a topological pumping cycle. “Same” means equivalent control parameters, timing distribution, optical loading, and environment within stated uncertainty.

The operation is selected because the candidate relation predicts differential susceptibility. If adjacency differs, the operation should depend on paths or couplings that distinguish adjacency while being insensitive to already matched projections. The sensitivity calculation is required before data collection.

The operation must not receive arm identity through an unintended channel. Separate waveform files, trigger delays, switch positions, or settling times can become covert labels. A compile-and-blind stage should produce control objects whose noncandidate statistics are balanced.

Chapter Twenty

The Independent Detector Bank

The detector bank should mix projections rather than multiply replicas. Useful channels include an optical spectrum analyzer, scanning Fabry–Pérot interferometer, heterodyne receiver, homodyne receiver, Mach–Zehnder interferometer, dual-comb system, fast photodiode with RF analysis, photon-counting detectors with time-correlated acquisition, total-power meter, absorptive calorimeter, optical vector network analyzer, and shared-clock digitizer.

No project needs every channel at once. Selection follows the causal model. For example, a power meter and calorimeter provide related but not identical energy projections. Heterodyne and direct detection respond differently to phase structure. Photon correlations probe statistics not retained in average power.

Each channel receives a saturation test, linearity test, dark record, reference input, bandwidth characterization, clock record, and calibration uncertainty. Channels that share preprocessing must be marked as dependent in the analysis.

Chapter Twenty One

Environmental and Artifact Controls

Temperature, vibration, acoustic noise, humidity, pressure, magnetic fields, electromagnetic interference, line power, optical reflection, and component self-heating can all correlate with experimental allocation. Monitoring should be chosen by plausible coupling, not by collecting decorative sensor streams.

The proposed enclosure may combine thermal control, vibration isolation and accelerometers, microphones, pressure and humidity sensing, magnetic and RF monitors, isolated power and line monitoring, reflection monitors, a thermal camera used during engineering, Faraday shielding, dark enclosures, a reference resonator, and a dummy optical path.

Environmental channels require their own calibrations and synchronization. A low-cost sensor with unknown delay can still be useful for discovery, but it cannot support precise causal exclusion. The apparatus should include deliberate perturbation tests: change temperature, inject vibration, alter RF exposure, and measure the signature each artifact produces.

Chapter Twenty Two

Timing Clocks and Event Order

Time labels often conceal several clocks: source phase, RF reference, acquisition clock, operating-system time, network time, and the order of hardware events. The experiment must say which clock supports which claim.

A field-programmable gate array or equivalent deterministic controller can distribute triggers and record hardware events. A common frequency reference reduces relative drift, while an independent clock provides a diagnostic against common reference failure. The full timing tree, delays, timestamp resolution, and resynchronization events belong in the archive.

Event order should be recorded independently of interpretive language. A relation described as “before” may mean trigger order, causal accessibility, timestamp order, or model parameter. This discipline prevents precausal hypotheses from being redescribed as retrocausality without an operational basis.

Chapter Twenty Three

The Minimum Viable Laboratory

A minimum serious classical setup includes one stable tunable laser, optical isolation and attenuation, polarization control, a fiber-ring resonator, phase and amplitude modulation, phase-coherent RF generation, an arbitrary waveform generator, a pulse shaper or equivalent programmable stage, optical spectral analysis, coherent detection, a total-power channel, environmental logging, deterministic timing, and an immutable data store.

The minimum is defined by claim closure, not price. If phase differences can explain the outcome, some coherent phase measurement is required. If heating can explain it, thermal monitoring and perturbation are required. If software allocation can leak, a blind compilation and event log are required.

A staged build is preferable: characterize each module; close ordinary transfer functions; demonstrate positive and negative controls; perform known-physics hidden-distinguishability trials; only then freeze the confirmatory protocol.

Chapter Twenty Four

Cold-Atom Replication

Cold atoms provide a second physical substrate for synthetic dimensions, using internal states, momentum states, or other controlled degrees of freedom as lattice sites. They introduce different preparation, decoherence, interaction, and detection mechanisms. Agreement with photonics would therefore be more informative than repetition on another optical bench.

The mapping must be frozen: what counts as a site, adjacency, path, projection, and second-stage susceptibility in both platforms? Platform-specific variables should not be erased in the name of analogy.

Cold-atom replication follows, rather than precedes, a successful photonic benchmark because it is operationally demanding. The goal is not prestige. It is to test whether the relational descriptor transports across different material realizations and measurement chains.

Part IV

Candidate Experiments

Chapter Twenty Five

Adjacency Multiplicity

Prepare two synthetic-frequency states with matched standard projections but different programmed coupling graphs. Apply a common operation sensitive to path multiplicity. Primary outcomes may include mode displacement, transition probability, phase response, pumping displacement, or transient decay.

The known-physics prediction should already distinguish the graphs when their full coupling matrices are included. The first experiment is therefore a benchmark of whether the verification bank can intentionally hide graph structure while the later operation reveals it. Success validates the experimental grammar, not FRTT.

Go criterion: preregistered recovery of the expected differential susceptibility across at least two detector projections. Stop criterion: the verification bank unintentionally distinguishes the preparations beyond tolerance, or leakage alone predicts the result.

Chapter Twenty Six

Coherence Density

Two preparations can share average populations or spectra while differing in the distribution of coherence across modes. Define a candidate coherence-density descriptor only after specifying basis, phase reference, estimator, and transformation behavior.

Apply an operation that converts distributed coherence into population or phase response. Heterodyne, interferometric, and photon-statistical channels can provide complementary projections. Ordinary quantum optics should explain the initial benchmark.

The experiment teaches an important lesson: a scalar total such as power can be equal while relational organization differs. The conclusion must remain about the specified state and measurement, not a universal hidden property.

Chapter Twenty Seven

Projection Loss and Aliasing Fidelity

Construct a richer state s and two projection chains Π_1 and Π_2 that intentionally discard different relations. Quantify which downstream interventions can still discriminate the original preparations. Define projection fidelity operationally as retained predictive performance, not resemblance to an assumed complete state.

Aliasing trials vary sampling, resolution, binning, and detector bandwidth. The objective is to map when distinct organizations collapse into one record and when later transformations recover a difference. These experiments directly connect Volume Two’s critique of units and representations to laboratory behavior.

The result is a detector map: a documented set of equivalence classes induced by each chain. It is useful even if no new physics is implicated.

Chapter Twenty Eight

Cross-Frame Invariants

Measure the same controlled preparation through two frames or lexicons—for example, time-domain and frequency-domain chains, or mode-space and path-space representations. Identify quantities that remain predictive after calibrated translation.

The FRTT question is whether a relational descriptor transports coherently across these local descriptions. The ordinary benchmark is supplied by Fourier relations, transfer matrices, and calibrated device physics. A claimed invariant must survive changes in sampling, reference phase, and representation without being a trivial conserved scalar.

Chapter Twenty Nine

Physical-Path Adjacency

Synthetic adjacency is enacted through programmed coupling. Physical-path adjacency uses distinct routes, components, or interaction neighborhoods. Prepare systems with matched input-output projections but different internal path structures, then apply a perturbation that couples locally to those structures.

This experiment tests whether a relational descriptor survives translation from programmed graph to material arrangement. Conventional scattering and network theory are the baseline. Apparatus asymmetry is a central nuisance and requires path swapping, device rotation, and reciprocal controls.

Chapter Thirty

Preparation-Provenance Erasure

Prepare the same apparent endpoint by two histories, then use the strongest available measurement bank to test endpoint equivalence. Apply a common operation whose outcome may depend on residual memory.

If standard theory predicts memory through unmeasured degrees of freedom, the result is conventional. The phrase “provenance erasure” therefore means erasure relative to a declared bank, not literal deletion of physical history.

The strongest version progressively expands the bank until the effect vanishes, stabilizes, or reveals a transportable descriptor. This prevents preparation history from being excluded by definition.

Chapter Thirty One

Relational Time and Dynamic Adjacency

Use multiple clocks and a time-dependent coupling graph. Analyze outcomes both by external time labels and by internal event relations. The goal is to determine whether a relational ordering offers predictive compression or invariance not supplied by one preferred clock.

Dynamic adjacency trials should vary the same graph at different rates and different graphs with matched scalar timing statistics. Conventional driven-system and Floquet models are the baseline. A recurrence relation must not be reduced automatically to periodic vibration; irregular or event-indexed returns are allowed.

Chapter Thirty Two

Residual Covariance Networks

After fitting the closed mainstream model, examine residuals jointly across detector and environmental channels. A candidate signal should have a preregistered covariance signature distinct from known common-mode disturbances.

Residual networks are dangerous because flexible graph discovery can find patterns in noise. Separate discovery and confirmation datasets, correct for multiplicity, and inject synthetic covariance signatures to validate recovery. A residual is a diagnostic until it repeats under intervention.

Chapter Thirty Three

Orientation and Potential Cross-Projections

Rotate or reorient a well-characterized apparatus and, separately, compare operation under different gravitational potentials available through conventional laboratory or site differences. Treat orientation, thermal loading, stress, magnetic field, fiber bending, and timing changes as primary ordinary explanations.

This family is not an early search for exotic gravity. It tests whether relational descriptors and detector equivalence transport across controlled frames. It proceeds only after local apparatus effects are characterized and after lower-level cross-frame benchmarks succeed.

Chapter Thirty Four

Nonlocal Correlation Without Communication

Distributed systems may exhibit correlations without enabling controllable communication. Any experiment in this family must preserve no-signaling tests and distinguish shared preparation, common causes, postselection, timing selection, and detector dependence.

The candidate question is whether a richer adjacency descriptor predicts correlation organization across independent projections. Bell-type language must be used precisely; violation of a classical inequality is not evidence for arbitrary superluminal influence. No communications claim follows without an operational channel and independently verified information transfer.

Chapter Thirty Five

Resource-Ledger Experiments

Instrument every control and reservoir sufficiently to test whether an apparent gain or unexplained response closes when reference frames, RF drive, heat, computation, and memory are included. Vary the accounting boundary prospectively and predict how the ledger should change.

The primary result is closure quality, not “free” energy or information. A robust unexplained residual must reproduce across boundary choices and independent calorimetric or electrical channels before becoming anomalous.

Chapter Thirty Six

Deferred High-Risk Claims

Inertial susceptibility, gravitational coupling, localization equivalence, and translation or teleportation-like proposals are explicitly deferred. They require the prior success of measurement equivalence, independent projection, resource closure, blind replication, and cross-platform transport.

Localization-equivalence work, if eventually reached, begins by asking whether two preparations occupy equivalent operational neighborhoods under a defined set of interactions. It does not begin by claiming matter transfer. Translation requires complete accounting of what physical carrier, state, resource, and identity criterion are transported.

Deferral is not dismissal. It prevents the most rhetorically powerful claims from consuming the evidentiary stages on which their meaning depends.

Part V

Evidence and Statistics

Chapter Thirty Seven

Equivalence Tolerances and Power

“No statistically significant difference” does not establish equivalence. A protocol must define the largest mismatch compatible with the later causal claim. Two one-sided tests, interval inclusion, or a suitable Bayesian decision rule may then test whether the difference lies within that margin.

The margin must be physical. If a 0.2 percent power difference could create the observed response, a 1 percent equivalence bound is useless. Sensitivity calculations propagate possible preparation mismatch through the operation to the outcome.

Power analysis must address both stages: power to establish preparation equivalence and power to detect the predicted post-intervention difference. Sequential monitoring, exclusions, and repeated calibration affect the error model and must be declared.

Chapter Thirty Eight

Testing Nonfactorization

A core FRTT candidate is that some predictive relation cannot be represented as independent scalar contributions within the tested model. Write a baseline factorization

$$p(y \mid x_1, \ldots, x_n) = F\left(f_1(x_1), \ldots, f_n(x_n)\right)$$

and a relational alternative containing interaction structure $R(x_i, x_j, \ldots)$. The alternative earns support only through out-of-sample prediction under new interventions.

Interaction terms in an ordinary statistical model are not automatically FRTT relations. Nonfactorization becomes scientifically interesting when the relational term is defined independently, transports across contexts, and outperforms flexible conventional alternatives without hidden data leakage.

Chapter Thirty Nine

Leakage Multiplicity and Overfitting

Leakage occurs when information about allocation or outcome enters preparation, acquisition, or analysis outside the proposed pathway. Checksums, filenames, waveform length, acquisition order, missingness, or preprocessing artifacts can all reveal the arm.

Multiplicity arises from many outcomes, detector channels, time windows, preprocessing variants, and candidate descriptors. A primary family and correction rule must be frozen. Exploratory analyses are preserved but separated.

Overfitting is especially dangerous when relational candidates are high-dimensional. Cross-validation within one dataset is insufficient if trials share drift or hardware state. Hold out sessions, devices, sites, and intervention types.

Chapter Forty

Causal Interpretation

An association becomes causal only relative to a model of interventions and exclusions. Randomization supports causal inference when allocation affects the outcome only through the intended treatment and when interference, attrition, and measurement changes are controlled.

The experimental graph should contain preparation, candidate relation, control resources, environment, operation, detector states, and report. Proposed adjustments must be justified by that graph. Blindly controlling every measured variable can bias the estimate.

The phrase “sensitive to α” should mean that controlled manipulation of the operationally defined α changes the outcome distribution while rival paths are bounded. It does not mean the apparatus touches an ontological object named α.

Chapter Forty One

Cross-Platform and Cross-Site Replication

Replication should preserve the question while allowing apparatus differences to test transport. A direct replication holds the protocol close. A conceptual replication realizes the same relational invariant through different hardware. Both are needed.

Sites should exchange frozen protocol packets, blinded test vectors, calibration artifacts, and analysis containers. Independent teams should be allowed to report nulls, protocol failures, and detector disagreement without being treated as adversaries.

Cross-site heterogeneity is modeled rather than averaged away. If the effect appears only under one detector architecture, that conditionality is a result requiring explanation.

Chapter Forty Two

The Claim Ladder

Level	Permitted claim
0	apparatus and analysis recover injected controls
1	two preparations are equivalent under a stated bank
2	a common operation distinguishes them reproducibly
3	a frozen relational descriptor predicts the distinction prospectively
4	the descriptor transports across detector, site, and platform
5	closed established models fail under independent replication
6	a conservative extension recovers old results and predicts new ones

Most early work belongs at Levels 0 through 2. Language from a higher level may not be borrowed for a lower-level result. “Anomaly,” “new invariant,” and “new physics” have progressively stronger obligations.

Chapter Forty Three

Failure and Null Results

A null result can mean the candidate has no leverage, the operation lacks sensitivity, equivalence was not established, noise was too large, or the model was wrong. The protocol must distinguish these possibilities where possible.

Stop conditions include failure of positive controls, unstable calibration, unclosed resources, allocation leakage, inability to establish equivalence, or a conventional variable that fully predicts the outcome. Continuing after a stop requires a new exploratory protocol, not silent modification.

If exhaustive sensitive interventions produce no differential susceptibility, the proposed relational degree has no demonstrated empirical leverage in that domain. This conclusion should be published. A theory that cannot lose information is not an empirical program.

Chapter Forty Four

Claim Packets

Every public result should be packaged with the claim, status level, protocol version, apparatus diagram, calibration and uncertainty, equivalence result, primary analysis, controls, deviations, raw-data manifest, code, resource ledger, alternative explanations, replication status, and explicit nonclaims.

The packet separates observation from interpretation. A detector difference can be preserved even when teams disagree about its cause. Contradictory replications remain linked rather than overwritten by consensus prose.

The packet is the unit of evidence integration on the website. Narrative pages may summarize it, but they may not replace it.

Part VI

The Operational Program

Chapter Forty Five

Protocol Template

A protocol begins with one sentence naming the comparison and one sentence naming what the result cannot establish. It then identifies the candidate tuple, baseline hierarchy, measurement bank, equivalence margins, intervention, outcomes, nuisance graph, controls, resource boundary, randomization, blinding, sample size, exclusions, analysis, stop conditions, archive, and claim level.

The protocol receives an immutable identifier and version. Amendments before data collection are allowed and logged. After confirmatory collection starts, material changes create a new protocol or are labeled deviations.

Chapter Forty Six

Data and Metadata Schema

Each trial record should contain stable identifiers for project, protocol, apparatus configuration, preparation, intervention, detector channels, calibration snapshot, clock state, environment, raw objects, exclusions, and blind allocation. Units are stored with quantity definitions and conversion provenance.

Relations should not be flattened unnecessarily into one spreadsheet. A graph or normalized schema can retain which calibration applies to which channel, which software produced which artifact, and which claim uses which evidence. Export formats should remain open and documented.

The minimum public metadata should allow another researcher to understand what was done even when raw data require staged release for legitimate safety, privacy, or proprietary reasons. Withholding must be explicit.

Chapter Forty Seven

The Gated Roadmap

Gate	Required achievement	Opens
G0	complete chain, hazards, calibrations, positive controls	pilot trials
G1	known-physics adjacency and coherence benchmarks	projection-loss studies
G2	blind equivalence and discrimination across independent detectors	frame and provenance studies
G3	dynamic, timing, residual, and orientation controls	cross-site replication
G4	transport to cold atoms or another substrate	candidate relational invariants
G5	repeated failure of closed conventional models	conservative extension tests
G6	recovery, prediction, and independent confirmation	cautiously stronger physical claims

Inertia and gravity remain beyond G5. Localization and translation remain beyond G6 and require additional safety, identity, and resource criteria. A failed gate redirects work downward to calibration, model closure, or candidate revision.

Chapter Forty Eight

The Website as Research Commons

The Substrate Cosmology website is the public navigation and evidence layer for this program. Begin with the volume links on the home page to learn the conceptual order. Use the model and glossary areas to inspect definitions. Use investigation routes for questions, protocols, and evidence records. Treat simulations and visualizations as thinking aids unless their pages identify empirical inputs.

For an experiment, create or locate the candidate question first. Attach a protocol packet before collecting confirmatory data. Preserve exploratory notes separately. When results arrive, add a claim packet that states evidence level, uncertainties, conflicts, and nonclaims. Link replications and negative results to the same question rather than creating a success-only narrative.

The evidence graph should preserve disagreement among detectors, teams, and sites. A summary may report the present balance, but source packets remain visible. Corrections create new versions with reasons. Significant contributors are credited for traceable work; AI assistance is disclosed without treating AI output as evidence.

The website does not confer validation. Publication to the commons means that a record can be inspected. It does not mean peer review, replication, endorsement, or incorporation into FRTT. The dedicated Volume Ten user manual will document every route, role, lifecycle, moderation boundary, continuity control, and export process in detail.

Conclusion

Measurement does not place a human observer outside the environment. It constructs a disciplined relation inside it. The apparatus prepares and perturbs; the detector partitions; calibration connects records; units summarize; language reports. These acts can reveal stable structure with extraordinary precision while still leaving other distinctions unavailable.

Substrate Cosmology does not ask researchers to abandon what can be seen. It asks them to see the seeing: the full physical and representational path by which a result became available. That shift makes conventional science more rigorous before it makes any new ontology plausible.

The experimental program begins with a modest achievement. Construct two known-physics preparations that are equivalent under a declared measurement bank, preserve a controlled relational difference, and reveal it through a common later operation. Do this blindly, with independent projections, calibrated uncertainty, closed resources, and a recoverable archive. Then repeat it across apparatus and platform.

If the program cannot pass those gates, stronger claims stop. If it can, the result is still not a license for metaphysical certainty. It is a better question—one whose answer was not decided in advance by a scalar, a unit, a coordinate, or the limitations of a single detector.

Appendix A

Measurement Chain Record

Field	Required record
Measurand	quantity, relation, interval, plane, bandwidth, and context
Preparation	recipe, hardware, settings, provenance, and known contingencies
Intervention	physical operation, timing, dose, and common-mode checks
Coupling	transfer mechanism and loading/back-action model
Transduction	detector principle, response, saturation, and bandwidth
Calibration	reference, date, fit, uncertainty, and traceability
Digitization	clock, rate, resolution, filters, firmware, and format
Environment	monitored variables, locations, rates, and calibration
Analysis	code version, parameters, exclusions, and random seeds
Report	estimator, uncertainty, units, rounding, plots, and claim level

Appendix B

Apparatus Architecture

Module	Representative components	Principal risks
Generation	tunable laser, reference, comb, isolator, attenuation, polarization	drift, back-reflection, hidden phase coupling
Synthetic lattice	resonator, modulators, RF sources, AWG	waveform leakage, dispersion, thermal shifts
Verification	power, spectrum, coherent phase, polarization	inadequate resolution, shared reference
Operation	second resonator, pulse shaper, programmable network	arm-dependent timing or loading
Detection	heterodyne, interferometer, photon counting, calorimetry	saturation, dead time, common preprocessing
Environment	thermal, vibration, acoustic, EM, power, reference path	unsynchronized or uncalibrated monitoring
Control	FPGA timing, randomizer, logger, blind key	allocation leakage, clock common cause
Archive	raw store, manifests, checksums, analysis environment	silent transformation, missing provenance

Appendix C

Preregistration Template

1. Research question and prohibited overclaim.
2. Candidate tuple and cross-platform mapping.
3. Mainstream baseline tiers and frozen version.
4. Preparation procedures and provenance.
5. Verification bank and equivalence margins.
6. Sensitivity model for the common intervention.
7. Primary and secondary outcomes.
8. Nuisance causal graph.
9. Positive, negative, sham, reference, and injection controls.
10. Randomization, blinding, blind-key custody, and unblinding rule.
11. Sample size, stopping rule, and missing-data handling.
12. Statistical model, multiplicity family, and robustness checks.
13. Resource boundary and ledger.
14. Exclusion and deviation rules.
15. Data, code, calibration, and metadata release plan.
16. Claim ladder ceiling and stop conditions.

Appendix D

Analysis Plan

The primary analysis should report preparation-equivalence intervals before post-intervention discrimination. It should then estimate the arm difference with uncertainty under the frozen model, followed by preregistered robustness models. Calibration uncertainty and dependence among channels must be propagated.

Secondary analysis may compare detectors, time windows, or candidate descriptors under a declared multiplicity correction. Exploratory analysis is stored in a separate namespace and labeled as hypothesis generating. A fresh dataset is required for confirmation.

Report effect sizes and prediction error, not only p values. Display individual sessions and apparatus states where practical. Preserve model failures, convergence warnings, excluded data, and all preregistered outcomes.

Appendix E

Detector Independence Assessment

Score each pair as shared, partially shared, or independent across transduction, physical path, reference standard, clock, power, environment, firmware, analysis code, operator, and laboratory. Explain every score. Do not combine channels as independent evidence when a plausible common failure dominates.

An independence claim should state its scope: “independent transduction with shared clock” is more informative than “two independent detectors.”

Appendix F

Stop and Go Criteria

Stop: positive control fails; calibration is outside validity; equivalence cannot be established; saturation or clipping occurs; allocation leaks; resource imbalance predicts outcome; baseline was changed after unblinding; primary result exists only after unregistered filtering; detector differences track a known artifact.

Go to replication: primary outcome passes; negative and sham controls remain bounded; signal injection is recovered; equivalence and sensitivity requirements are both met; at least two materially different projections support the result; conventional models and resources are closed to the declared level; the archive regenerates the report.

Go to stronger interpretation: direct replication, conceptual replication, cross-site and cross-platform transport, prospective prediction by a frozen relational descriptor, and independent failure of closed established models.

Appendix G

Language and Evidence Status

Avoid	Use instead
detected another dimension	discriminated two preparations with different programmed adjacency
proved the substrate	supported a specified model under tested interactions
same state	equivalent under the stated measurement bank and tolerance
independent detectors	detectors independent across the listed mechanisms
no difference	interval bounded within a preregistered equivalence margin
impossible in relativity	not represented by the tested relativistic model; recovery remains required
retrocausal	event-order dependence under the defined clocks and interventions
free energy/information	residual under the stated resource boundary
teleportation	deferred localization or translation protocol with explicit carriers and resources

Appendix H

Glossary

Actual Physics: the unknown physical target, used to prevent representations from being mistaken for the totality of what exists.

Candidate freeze: the preregistered operational definition of a proposed relational variable before confirmatory data.

Claim packet: a versioned bundle linking a claim to protocol, evidence, uncertainty, alternatives, and nonclaims.

Detector-induced equivalence: indistinguishability under a specified detector-and-analysis chain within a justified tolerance.

Independent projection: a measurement channel that retains different distinctions and does not share the decisive failure mechanism.

Measurement bank: the declared set of channels used to establish operational equivalence.

Nonfactorization: failure of a specified independent-component model, not generic mathematical complexity.

Projection: a physical or representational operation that makes some distinctions available while merging others.

Relational carrier: the minimal declared system on which candidate objects, relations, operations, and projections are defined.

Resource ledger: bounded accounting of physical and informational resources entering, leaving, and organizing an experiment.

Synthetic dimension: an effective lattice coordinate formed from controllable states or modes; not by itself an ontological extra dimension.

Appendix I

Sources References and Collaboration Record

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AI Collaboration Record

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