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LFM Comprehensive Report

Generated: 2025-11-02 21:24:43

This document combines: - Governing documents (Executive Summary, Master, Core Equations, Phase 1 Test Design) - Test results rollup - Tier and per-test descriptions with pass/fail status

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Executive Summary

Lattice-Field Medium (LFM): Executive Summary

Version 3.0 — 2025-11-01 (Defensive ND Release)
Greg D. Partin | LFM Research — Los Angeles CA USA

Note: This version supersedes all prior releases (v3.0 and earlier) and adds No-Derivatives restrictions and defensive-publication language for intellectual-property protection. All LFM Phase-1 documents are synchronized under this unified v3.0 release.

Overview

The Lattice-Field Medium (LFM) proposes that spacetime itself is a discrete, deterministic lattice of locally interacting cells. Each cell carries an energy amplitude $E(x,t)$ and a curvature parameter $\chi(x,t)$ that modulates its local stiffness. The governing relation $\partial^2E/\partial t^2 = c^2\nabla^2E - \chi^2(x,t)E$, with $c^2 = \alpha/\beta$, represents a Lorentz-symmetric, locally causal wave law. By allowing χ to vary across space and time, this single rule reproduces classical mechanics, relativity, gravitation, quantization, and cosmological expansion as emergent phenomena of one underlying field.

Key Structural Features

Feature	Consequence
Local hyperbolic operator	Finite propagation speed and causality
Lorentz invariance in continuum limit	Special relativity emerges automatically
Curvature field $\chi(x,t)$	Acts as both inertial mass and gravitational potential
Lagrangian & Noether conservation	Intrinsic energy–momentum conservation
Discrete temporal steps	Natural quantization scale ($\hbar_{eff} = \Delta E_{min} \Delta t$)

Recent Results (Validated Tiers)

1. Lorentz analogue confirmed numerically ($\omega^2 = c^2k^2 + \chi^2$).
2. Gravitational redshift and lensing reproduced with χ-gradients (Tier 2).
3. Energy conservation stable to $<10^{-4}$ drift over 10^3 steps.
4. Cosmological expansion self-limits via χ-feedback (Tier 6 prototype).
5. Variational gravity law derived: $\sigma\_\chi(\partial_t^2\chi - v\_\chi^2\nabla^2\chi) + V'(\chi) = g\_\chi E^2 + \kappa\_EM(|\mathfrak{E}|^2 + c^2|\mathfrak{B}|^2)$.

Implications

- Unified framework: Relativity, gravitation, and quantization emerge from one discrete rule.
- Conceptual simplicity: No additional dimensions or forces required—space itself is the lattice.
- Predictive potential: χ-feedback may eliminate the need for a cosmological constant.
- Philosophical significance: Information conservation and time's arrow arise intrinsically.

Status and Next Steps

All core equations and validation tiers are internally consistent. Phase 1 establishes full reproducibility through deterministic GPU-based tests. Next steps include expanded electromagnetic simulations, extended quantum interference validation, and long-run χ-feedback stability studies.

Summary

The LFM shows that many fundamental laws can emerge from a single deterministic cellular substrate. Gravity, inertia, and relativistic behavior are not imposed upon the lattice—they are expressions of its geometry. Upon completion of Tier 3 validation and expert review, the LFM will stand as a mathematically coherent, testable, and potentially unifying framework for physical law.

Legal & Licensing Notice

Citation (Zenodo Record):
Partin, G. D. (2025). *Lattice-Field Medium (LFM): A Deterministic Lattice Framework for Emergent Relativity, Gravitation, and Quantization — Phase 1 Conceptual Hypothesis v1.0*. Zenodo. https://doi.org/10.5281/zenodo.17478758

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Master Document

Lattice-Field Medium (LFM): Master Document — Conceptual Framework and Physical Interpretation Version 3.0 — 2025-11-01 (Defensive ND Release)
Greg D. Partin | LFM Research, Los Angeles CA USA

Note: This version supersedes all prior releases (v2.x and earlier) and adds No-Derivatives restrictions and defensive-publication language for intellectual property protection. All LFM Phase-1 documents are synchronized under this unified v3.0 release.

Abstract

The Lattice-Field Medium (LFM) proposes that spacetime arises from a deterministic lattice of locally coupled energy cells. Each cell evolves according to a single discrete update rule that yields, in the continuum limit, a variable-mass Klein–Gordon equation. This master document provides the conceptual framework and interpretation of that rule, showing how classical, relativistic, gravitational, quantum, and cosmological behaviors all emerge as consequences of one substrate law.

1 Purpose and Scope

This document defines the conceptual framework of the Lattice-Field Medium (LFM) and connects it to the formal equations and numerical tests in the companion Core Equations and Phase 1 Test Design documents. Its goal is to describe how physical laws emerge from local lattice dynamics and to outline the interpretive consequences for relativity, gravitation, and quantization.

2 Canonical Framework

At the foundation of the LFM is a local deterministic equation that governs the evolution of the energy field E(x,t) and curvature field χ(x,t):

$$\partial^2 E/\partial t^2 = c^2 \nabla^2 E - \chi(x,t)^2 E, \quad \text{with} \quad c^2 = \alpha/\beta.$$

This is the same canonical law implemented in the discrete leapfrog form defined in the companion LFM Core Equations (v1.1).

This relation represents a Lorentz-symmetric, locally causal wave equation. In the continuum limit, it reproduces the structure of a variable-mass Klein–Gordon field. All macroscopic behaviors—classical, relativistic, and quantum—arise from this same rule.

3 Foundational Properties

Structural Feature	Physical Outcome
Local hyperbolic operator	Finite propagation speed, causality
Lorentz invariance of □	Emergent special relativity
Curvature field χ(x,t)	Inertia and gravity analogues
Lagrangian symmetry	Energy–momentum conservation
Discrete time step defines a natural quantization scale ($\hbar$_eff = ΔE_min Δt).	Natural quantization scale

4 Analytic Checks and Validation

Analytic proofs demonstrate that the LFM reproduces well-known physical laws:
1. Characteristic cone: defines invariant light-cone structure.
2. Noether energy: ensures intrinsic conservation.

3. WKB lensing: predicts ray bending toward higher χ.
4. Mode quantization: discrete oscillation frequencies.
5. Scaling symmetry: dimensionless and self-consistent.

5 Domains of Emergence

The same lattice rule reproduces distinct physical regimes depending on the behavior of χ(x,t) and coupling constants:

• Classical & Relativistic: Lorentz invariance and causal propagation (Tier 1).

• Gravitational: χ-gradients produce redshift and lensing (Tier 2).

• Quantum & Coherence: quantized exchange and long-range correlations (Tier 3–5).

• Cosmological: χ-feedback drives self-limiting expansion (Tier 6).

(Tier numbering corresponds to Phase 1 Test Design v2.0.)

6 Interpretation and Ontology

In the LFM view, spacetime, matter and energy are emergent manifestations of a discrete substrate:
- Space corresponds to lattice connectivity.
- Time corresponds to sequential updates.
- Energy corresponds to local oscillation amplitude.
- Gravity arises from spatial gradients in χ.
- Quantization results from discrete temporal evolution.

Fig 1 — Conceptual mapping of LFM quantities to physical observables (placeholder).

7 Experimental and Simulation Validation

Domain	Example Test	Observable	Status
Laboratory	Cavity or interferometer	Discrete dispersion / anisotropy	Planned
Astrophysical	GRB timing / ringdown	χ-dependent delay or shift	Analysis
Numerical	Tier 1–3 GPU lattice runs	Lorentz & energy conservation	PASS

8 Gravity Emergence Summary

The curvature field χ acts as a dynamic gravitational potential. Its equation of motion, derived from the Lagrangian formalism, reproduces the Newtonian limit and predicts weak-field lensing and redshift effects. In this view, gravity is a self-organized property of the lattice rather than an external force.

(These gravitational analogues arise in Tier 2 configurations and above; no new forces or parameters are introduced.)

9 The Nature of Time

The LFM update law is time-symmetric, but the arrow of time arises from information dispersion. As correlations spread across more lattice cells, entropy increases. Thus, time measures the diffusion of information rather than an independent external flow.

The increase in entropy noted here corresponds to the measurable entropy dynamics diagnostic in simulation output.

This interpretation is consistent with reversible yet statistically asymmetric evolution, where microscopic reversibility yields macroscopic time's arrow.

10 Continuum–Discrete Bridge

Fluid behavior, wave mechanics, and quantum interference all appear as statistical regimes of the same discrete rule. By tuning α, β, and χ (and optional damping γ), the lattice reproduces laminar, turbulent, and quantized flow behaviors consistent with classical hydrodynamics and quantum statistics.

11 Tier-1 Insights

Tier-1 validation confirms that discrete, reversible rules can reproduce continuous, isotropic energy propagation with conservation to numerical precision. This implies that continuity itself is an emergent illusion of discrete processes.

Key outcomes:
- Conservation from discreteness
- Emergent relativity
- Self-quantization
- Continuum illusion

Together, these show that the lattice substrate can generate stable, law-like behavior indistinguishable from continuous spacetime.

These validations establish the canonical Tier 1–3 foundation on which all higher-tier phenomena build.

12 Open Questions and Future Work

Outstanding questions for future investigation:
1. Mapping lattice constants (α, β, χ) to physical units.
2. High-curvature stability and 3D scalability.
3. Independent third-party validation.
4. Entropy, thermodynamics, and information conservation.
5. Integration with established quantum field frameworks.

6. Long-term numerical energy drift characterization across different stencil orders and dimensions.

7. Verification of χ-coupled energy curvature via probe-particle simulations (Tier 2–3 extensions).

13 Summary

The Lattice-Field Medium unifies relativity, gravitation, quantization, and cosmology through a single discrete rule. Energy, inertia, and curvature emerge as properties of one deterministic field. Continued validation will determine whether this structure can serve as a fundamental framework for physical law.

This Version aligns all conceptual, mathematical, and numerical formulations under one canonical framework, thereby completing Phase 1 conceptual validation and establishing the theoretical foundation for empirical verification.

14 Legal & Licensing Notice

Citation (Zenodo Record):
Partin, G. D. (2025). *Lattice-Field Medium (LFM): A Deterministic Lattice Framework for Emergent Relativity, Gravitation, and Quantization — Phase 1 Conceptual Hypothesis v1.0*. Zenodo. https://doi.org/10.5281/zenodo.17478758

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Core Equations

Lattice-Field Medium (LFM): Core Equations and Theoretical Foundations Version 3.0 — 2025-11-01 (Defensive ND Release)

Greg D. Partin | LFM Research — Los Angeles CA USA Note: This version supersedes all prior releases (v1.x and v2.x) and adds No-Derivatives restrictions and defensive-publication language for intellectual property protection. All LFM Phase-1 documents are synchronized under this unified v3.0 release.

Abstract

This document defines the governing equations of the Lattice-Field Medium (LFM) and their continuum, discrete, and variational forms. It establishes the connection between the lattice update law and the variable-mass Klein–Gordon equation, outlines how Lorentz invariance emerges naturally in the continuum limit, and shows how quantization and gravitational analogues arise through the curvature field χ(x,t).

1 Introduction and Scope

The Lattice-Field Medium (LFM) treats spacetime as a discrete lattice of interacting energy cells. Each cell holds an energy amplitude $E(x,t)$ and curvature parameter $\chi(x,t)$. The purpose of this document is to define the mathematical foundation of LFM, connecting the discrete rule to its continuum form and providing validation targets used in Tier 1–3 testing.

2 Canonical Field Equation

The canonical continuum form of the LFM equation is:

$$\partial^2E/\partial t^2 = c^2\, \nabla^2E - \chi^2(x,t)\, E, \qquad \text{with} \quad c^2 = \alpha/\beta.$$

Here $E(x,t)$ is the local field energy, $\chi(x,t)$ is the curvature (effective mass), and c is the lattice propagation speed.

3 Discrete Lattice Update Law

We use a second-order, leapfrog scheme consistent with the canonical field equation

$$\partial^2E/\partial t^2 = c^2\nabla^2E - \chi(x,t)^2\, E, \quad \text{with} \quad c^2 = \alpha/\beta.$$

where ∇_Δ^2 is the finite-difference Laplacian, $\gamma \geq 0$ is optional numerical

damping ($\gamma = 0$ for conservative runs), and $\chi(x,t)$ may be a scalar or a spatial field.

$$E\text{\^{}}\{t+1\} = (2 - \gamma)\, E\text{\^{}}t - (1 - \gamma)\, E\text{\^{}}\{t-1\}$$

$$+ (\Delta t)^2\, [\, c^2\, \nabla\_\Delta^2\, E\text{\^{}}t - \chi(x,t)^2\, E\text{\^{}}t\,]\,,$$

1D Laplacian (order-2):

$$\nabla\_\Delta^2\, E\_i = (E\_\{i+1\} - 2E\_i + E\_\{i-1\}) / (\Delta x)^2$$

1D Laplacian (order-4):

$$\nabla\_\Delta^2\, E\_i = [-E\_\{i+2\} + 16E\_\{i+1\} - 30E\_i + 16E\_\{i-1\} - E\_\{i-2\}] / (12\, (\Delta x)^2)$$

Multi-D:

- 2D supports order-2 and order-4.
- 3D currently supports order-2 only (order-4/6 reserved for future tiers).

Boundary options (per test): periodic (canonical), reflective, or absorbing.

No stochastic (η) or exogenous coupling (Δφ) terms are part of the canonical law.

4 Derived Relations and (Continuum vs Lattice)

Continuum dispersion (χ constant):

$\omega^2 = c^2 k^2 + \chi^2$

Lattice dispersion (order-2 1D; used in Tier-1 validation):

$\omega^2 = (4 c^2 / \Delta x^2) \sin^2(k \Delta x / 2) + \chi^2$

Energy monitoring (numerical):

We track relative energy drift $|\Delta E| / |E_0|$ and target $\leq 10^{-6} \ldots 10^{-4}$ depending on grid and BCs.

Exact conservation holds in the continuum; simulations measure small drift.

Quantized exchange (interpretive):

$\Delta E = n\, \hbar_{eff}$ with $\hbar_{eff} = \Delta E_{min}\, \Delta t$ arising from discrete time; this is interpretive, not an input law.

Cosmological feedback:

Terms such as $E_{t+1} = E_t + \alpha \nabla^2 E - nH\, E$ belong to higher-tier χ-feedback studies and are not part of the canonical kernel.

5 Analogues (Non-canonical, exploratory)

Electromagnetic and inertial behaviours can be constructed as analogues of the canonical kernel, but they are not part of it.

The following discrete Maxwell-like updates are included for context only and belong in Appendix A (Analogues).

Discrete EM Coupling (Eq. 5-1, 5-2):

$E_{I,t+1} = E_{I,t} + \alpha(\phi_{i+1,t} - \phi_{i-1,t}) - \beta B_{I,t}$

$B_{I,t+1} = B_{I,t} + \beta(\phi_{i+1,t} - \phi_{i-1,t}) + \alpha E_{I,t}$

6 Lorentz Continuum Limit

Starting from the discrete update rule and applying Taylor expansion in time, the LFM equation reduces to:

$\partial^2E/\partial t^2 = c^2\, \nabla^2 E$,   with $c^2 = \alpha/\beta$.

This form is invariant under Lorentz transformations, demonstrating that relativity emerges naturally from local lattice dynamics.

Formally, this corresponds to the joint limit $\Delta x, \Delta t \to 0$ (with $c = \Delta x/\Delta t$ fixed), where $\Sigma\, E_i\, \Delta x \to \int E(x)\, dx$ over $(-\infty,+\infty)$.

7 Quantization from Discreteness

Quantization arises from the finite time-step Δt. The minimal exchange of energy per step defines $\hbar_{eff} = \Delta E_{min}\, \Delta t$. The energy–frequency relation becomes $E = \hbar_{eff}\, \omega$, and the momentum–wavelength relation $p = \hbar_{eff}\, k$, reproducing the de Broglie relation.

8 Dynamic χ Feedback and Cosmological Scaling

The curvature field χ evolves according to the feedback law:

$d\chi/dt = \kappa(\rho_{ref} - \rho_E) - \gamma\, \chi\, \rho_E$.

This rule produces self-limiting cosmic expansion and links local energy density to curvature dynamics.

Edge-creation condition:
if $|\partial E/\partial r| > E_{th}$ → new cell at boundary.

This mechanism replaces the classical singular Big Bang with a deterministic expansion cascade.

9 Variational Gravity for χ

Promoting χ to a dynamic field yields coupled Euler–Lagrange equations:

$\sigma_\chi(\partial_t^2\chi - v_\chi^2\nabla^2\chi) + V'(\chi) = g_\chi E^2 + \kappa_{EM}(|\mathfrak{E}|^2 + c^2|\mathfrak{B}|^2)$.

In the weak-field limit, $\nabla^2\Phi = 4\pi G_{eff}\rho_{eff}$ reproduces Newtonian gravity and redshift/lensing analogues.

10 Numerical Stability and Validation

CFL stability (d spatial dimensions):

$c\,\Delta t / \Delta x \le 1 / \sqrt{d} \quad (d = 1, 2, 3)$

Energy diagnostics:

Measure $|\Delta E| / |E_0|$ each run; typical tolerances $\le 10^{-6} – 10^{-4}$ depending on Δx, Δt, stencil order, and boundary conditions.

Stencil availability:

1D / 2D → order-2 and order-4; 3D → order-2 only (order-4 / 6 reserved for future tiers).

Test alignment:

Tier-1 uses the lattice dispersion relation above;

Tier-2 uses static χ(x) gradients;

Tier-3 evaluates energy drift under conservative settings.

11 Relation to Known PDE Classes

PDE Class	Canonical Form	Relation to LFM	Reference
Klein–Gordon	$E_{tt} - c^2\nabla^2 E + m^2 E = 0$	LFM with constant χ	—
Variable-mass KG	$E_{tt} - c^2\nabla^2 E + \chi(x,t)^2 E = 0$	Identical continuum form	Ebert & Nascimento (2017)
Helmholtz	$\nabla^2 u + k_{eff}^2(x) u = 0$	Time-harmonic analogue	Yagdjian (2012)
Quantum-walk lattices	Discrete Dirac/KG	Emergent Lorentz symmetry	Bisio et al. (2015)

12 Summary and Outlook

The Lattice-Field Medium provides a deterministic, Lorentz-symmetric framework where quantization, inertia, gravity, and cosmic expansion emerge from one discrete rule. All formulations preserve conservation, isotropy, and CPT symmetry. Tier 1–3 validations confirm numerical stability and physical coherence, forming the foundation for higher-tier exploration.

The canonical PDE remains fixed across all tiers; all higher-tier phenomena emerge from this equation without modification.

13 Legal & Licensing Notice

Citation (Zenodo Record):
Partin, G. D. (2025). *Lattice-Field Medium (LFM): A Deterministic Lattice Framework for Emergent Relativity, Gravitation, and Quantization — Phase 1 Conceptual Hypothesis v1.0*. Zenodo. https://doi.org/10.5281/zenodo.17478758

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Phase 1 Test Design

Lattice-Field Medium (LFM): Phase 1 Test Design — Proof-of-Concept Validation System

Version 3.0 — 2025-11-01 (Defensive ND Release)
Greg D. Partin | LFM Research — Los Angeles CA USA

Note: This version supersedes all prior releases (v2.x and earlier) and adds No-Derivatives restrictions and defensive-publication language for intellectual property protection. All LFM Phase-1 documents are synchronized under this unified v3.0 release.

Abstract

Phase 1 defines the design and implementation framework for validating the Lattice-Field Medium (LFM) through reproducible Tier 1–3 tests. It specifies the environment, configuration architecture, pass/fail criteria, and proof-packet generation protocol required to establish numerical and physical correctness of the model. This version modernizes the document layout for reproducibility and OSF publication compliance.

1 Purpose

Phase 1 establishes the full architecture for the LFM Proof-of-Concept Validation System. The goal is to provide a reproducible testing environment that demonstrates Tier 1–3 correctness and creates a foundation for higher-tier extensions and expert review.

2 Hardware and Environment

Component	Specification	Notes
System	MSI Katana A15 AI	Primary development node
CPU / GPU	Ryzen 7 8845HS / RTX 4060 (8 GB VRAM)	Tier 6-capable hardware
RAM / Storage	32 GB / 1 TB SSD	Sufficient for 3D Tier 3 tests

Component	Specification	Notes
OS	Windows 11 x64	
Python Environment	3.11.9 + NumPy, SciPy, Numba, CuPy-CUDA12x	Standard computation stack
Version Control	Git (local → GitHub private)	Ensures provenance and reproducibility

3 Folder and File Architecture

The LFM Proof-of-Concept environment follows a strict folder structure:
LFM\code — Source modules and Tier kernels
LFM\config — JSON configuration and thresholds
LFM\runs — Runtime data for each experiment
LFM\results — Metrics, plots, and summaries
LFM\logs — Execution and environment logs
LFM\packages — Proof-packet archives

4 Configuration and Validation Logic

Global tolerances reside in /config/validation_thresholds.json, with Tier-specific overrides in /config/tierN_default.json. Merge order: global → local → runtime. Configuration keys include tier, parameters, tolerances, run_settings, and notes.

5 Pass/Fail Framework

Tier	Goal	Pass Criteria
1	Lorentz isotropy & dispersion	$\Delta v/c \le 1$ %, anisotropy ≤ 1 %, energy drift ≤ 1×10^{-6}
2	Weak-field / redshift analogue	Correlation > 0.95 with analytic model; drift ≤ 1 %
3	Energy conservation	$\lvert\Sigma\Delta E\rvert / \Sigma E < 1e-12$

6 Orchestration and Parallelism

The master script run_all_tiers.py references /config/orchestration.json to schedule tiers and variants with a concurrency limit (default 3). Each run executes run_tier.py, writes results, and aggregates metrics into /results/<campaign>/summary_overall.json.

7 Visualization and Reporting

Plots auto-generate under /results/<campaign>/<tier>/<variant>/plots/. Each follows scientific styling standards (energy_vs_time, anisotropy_vs_time, etc.). A summary dashboard (summary_dashboard.html) compiles all Tier results.

8 Expert Review Packaging Workflow

After all Tier tests complete, the system assembles a proof packet in /packages/LFM_ProofPacket_<campaign>_vX.Y.zip. Each archive contains README, manifest, environment info, configs, code snapshot, results, logs, and SHA-256 hashes. Integrity checks and optional Cardano anchoring ensure reproducibility.

9 Phase 1 Test Scope

Phase 1 executes 26 Tier 1–3 tests: 9 Relativistic, 8 Gravity-Analogue, and 9 Energy-Conservation tests. Expected duration: ~6 weeks with full parallelization.

10 Data Reproducibility and Licensing

All code and data products are released under CC BY-NC 4.0 (non-commercial, attribution required).. Each result file includes environment hashes and deterministic seeds. Reproducibility requires the same configuration files and random seed identifiers as recorded in the proof packets.

11 Metadata Alignment

Field	Value
Keywords	lattice field theory; discrete spacetime; emergent relativity; reproducibility; computational physics
License	License CC BY-NC 4.0 (non-commercial, attribution required)
Category Tags	Theoretical Physics · Computational Physics · Simulation Frameworks
Data Availability	All proof packets and logs provided as supplemental data under reproducible archive.
Funding / Acknowledgements	Self-funded; no external sponsors.
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12 Summary

Phase 1 provides the reproducibility framework for all Tier 1–3 LFM tests. It defines configuration structure, orchestration logic, validation thresholds, and proof-packet packaging. Successful completion confirms the model’s stability, isotropy, and conservation—forming the empirical base for Tier 4–6 development.

13 Legal & Licensing Notice

Citation (Zenodo Record):
Partin, G. D. (2025). *Lattice-Field Medium (LFM): A Deterministic Lattice Framework for Emergent Relativity, Gravitation, and Quantization — Phase 1 Conceptual Hypothesis v1.0.* Zenodo. https://doi.org/10.5281/zenodo.17478758

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Test Results Rollup

```
MASTER TEST STATUS REPORT - LFM Lattice Field Model
Generated: 2025-11-02 21:24:41
Validation Rule: Suite marked NOT RUN if any test missing from CSV

CATEGORY SUMMARY
Tier,Category,Expected_Tests,Tests_In_CSV,Status,Pass_Rate
Tier 1,Relativistic,15,15,PASS,15/15 passed
Tier 2,Gravity Analogue,25,24,PARTIAL,21/24 passed - 3 skipped - 1 missing
Tier 3,Energy Conservation,11,10,PASS,10/10 passed - 1 missing
Tier 4,Quantization,9,14,PASS,14/14 passed

DETAILED TEST RESULTS

TIER 1 - RELATIVISTIC (15/15 tests)
Test_ID,Description,Status,Notes
REL-01,Isotropy — Coarse Grid,PASS,
REL-02,Isotropy — Fine Grid,PASS,
REL-03,Lorentz Boost — Low Velocity,PASS,
REL-04,Lorentz Boost — High Velocity,PASS,
REL-05,Causality — Pulse Propagation,PASS,
REL-06,Causality — Noise Perturbation,PASS,
REL-07,Phase Independence Test,PASS,
REL-08,Superposition Principle Test,PASS,
REL-09,3D Isotropy — Directional Equivalence,PASS,
REL-10,3D Isotropy — Spherical Symmetry,PASS,
REL-11,Dispersion Relation — Non-relativistic (χ/k≈10),PASS,
REL-12,Dispersion Relation — Weakly Relativistic (χ/k≈1),PASS,
REL-13,Dispersion Relation — Relativistic (χ/k≈0.5),PASS,
REL-14,Dispersion Relation — Ultra-relativistic (χ/k≈0.1),PASS,
REL-15,Causality — Space-like correlation test (light cone violation check),P
ASS,

TIER 2 - GRAVITY ANALOGUE (24/25 tests)
Test_ID,Description,Status,Notes
GRAV-01,Local frequency — linear χ-gradient (weak),PASS,
GRAV-02,Local frequency — Gaussian well (strong curvature),PASS,
GRAV-03,Local frequency — Gaussian well (broader potential),PASS,
GRAV-04,Local frequency — Gaussian well (shallow potential),PASS,
GRAV-05,Local frequency — linear χ-gradient (moderate),PASS,
GRAV-06,Local frequency — Gaussian well (stable reference),PASS,
GRAV-07,Time dilation — bound states in double-well potential (KNOWN: Packet
becomes trapped; demonstrates bound state physics),SKIP,Exploratory: bound-st
ate measurement pending; packet trapping
GRAV-08,Time dilation — uniform χ diagnostic (isolate grid dispersion),PASS,
GRAV-10,Gravitational redshift — measure frequency shift in 1D potential well,
PASS,
GRAV-11,Time delay — packet through χ slab (Shapiro-like) (NEEDS DEBUG: Packe
```

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t tracking measurement issues),SKIP,Packet tracking diagnostics WIP; Shapiro-like delay measurement
GRAV-12,Phase delay — continuous wave through χ slab (DEMONSTRATES: Klein-Gordon phase/group velocity mismatch - testable prediction!),PASS,
GRAV-13,Local frequency — double well (ω∝χ verification),PASS,
GRAV-14,Group delay — differential timing with vs without slab (NEEDS DEBUG: Signal too weak to measure delay),SKIP,Signal too weak for robust differential timing with current setup
GRAV-15,3D radial energy dispersion visualizer — central excitation; volumetric snapshots for MP4,PASS,
GRAV-16,3D double-slit interference — quantum wave through slits showing χ-field localization,PASS,
GRAV-17,Gravitational redshift — frequency shift climbing out of χ-well,PASS,
GRAV-18,Gravitational redshift — linear gradient (Pound-Rebka analogue),PASS,
GRAV-19,Gravitational redshift — radial χ-profile (Schwarzschild analogue),PASS,
GRAV-20,Self-consistent chi from E-energy (Poisson) - verify omega~=chi at center (1D),PASS,
GRAV-21,GR calibration - redshift to G_eff mapping (weak-field limit),PASS,
GRAV-22,GR calibration - Shapiro delay correspondence (group velocity through slab),PASS,
GRAV-23,Dynamic χ-field evolution — full wave equation □χ=-4πGρ with causal propagation (gravitational wave analogue),PASS,
GRAV-24,Gravitational wave propagation — oscillating source radiates χ-waves; validate 1/r decay and propagation speed,PASS,
GRAV-25,Light bending — ray tracing through χ-gradient; measure deflection angle,PASS,
```

TIER 3 - ENERGY CONSERVATION (10/11 tests)

```
Test_ID,Description,Status,Notes
ENER-01,Global conservation — short,PASS,
ENER-02,Global conservation — long,PASS,
ENER-03,Wave integrity — mild curvature,PASS,
ENER-04,Wave integrity — steep curvature,PASS,
ENER-05,Hamiltonian partitioning — uniform χ (KE ↔ GE flow),PASS,
ENER-06,Hamiltonian partitioning — with mass term (KE ↔ GE ↔ PE flow),PASS,
ENER-07,Hamiltonian partitioning — χ-gradient field (energy flow in curved spacetime),PASS,
ENER-08,Dissipation — weak damping (exponential decay; γ=1e-3 per unit time),PASS,
ENER-09,Dissipation — strong damping (exponential decay; γ=1e-2 per unit time),PASS,
ENER-10,Thermalization — noise + damping reaches steady state,PASS,
```

TIER 4 - QUANTIZATION (14/9 tests)

```
Test_ID,Description,Status,Notes
QUAN-01,ΔE Transfer — Low Energy,PASS,
QUAN-02,ΔE Transfer — High Energy,PASS,
QUAN-03,Spectral Linearity — Coarse Steps,PASS,
QUAN-04,Spectral Linearity — Fine Steps,PASS,
```

```
QUAN-05,Phase-Amplitude Coupling — Low Noise,PASS,
QUAN-06,Phase-Amplitude Coupling — High Noise,PASS,
QUAN-07,Nonlinear Wavefront Stability,PASS,
QUAN-08,High-Energy Lattice Blowout Test,PASS,
QUAN-09,Heisenberg uncertainty — Δx·Δk ≈ 1/2,PASS,
QUAN-10,Bound state quantization — discrete energy eigenvalues E_n emerge from boundary conditions,PASS,Discrete energy eigenvalues emerge from boundary conditions - fundamental quantum signature
QUAN-11,Zero-point energy — ground state E₀ = ½ℏω ≠ 0 (vacuum fluctuations),PASS,
QUAN-12,Quantum tunneling — barrier penetration when E < V (classically forbidden),PASS,Quantum tunneling demonstrated - wave penetrates classically forbidden barrier
QUAN-13,Wave-particle duality — which-way information destroys interference,PASS,
QUAN-14,Non-thermalization — validates Klein-Gordon conserves energy (doesn't approach Planck),PASS,
```

Tier and Test Descriptions

Tier 1 — Relativistic (Lorentz invariance, isotropy, causality)

REL-01: Isotropy — Coarse Grid

Status: PASS

REL-02: Isotropy — Fine Grid

Status: PASS

REL-03: Lorentz Boost — Low Velocity

Status: PASS

REL-04: Lorentz Boost — High Velocity

Status: PASS

REL-05: Causality — Pulse Propagation

Status: PASS

REL-06: Causality — Noise Perturbation

Status: PASS

REL-07: Phase Independence Test

Status: PASS

REL-08: Superposition Principle Test

Status: PASS

REL-09: 3D Isotropy — Directional Equivalence

Status: PASS

REL-10: 3D Isotropy — Spherical Symmetry

Status: PASS

REL-11: Dispersion Relation — Non-relativistic ($\chi/k \approx 10$)

Status: PASS

REL-12: Dispersion Relation — Weakly Relativistic ($\chi/k \approx 1$)

Status: PASS

REL-13: Dispersion Relation — Relativistic ($\chi/k \approx 0.5$)

Status: PASS

REL-14: Dispersion Relation — Ultra-relativistic ($\chi/k \approx 0.1$)

Status: PASS

REL-15: Causality — Space-like correlation test (light cone violation check)

Status: PASS

Tier 2 — Gravity Analogue (χ-field gradients, redshift, lensing)

GRAV-01: Local frequency — linear χ-gradient (weak)

Status: PASS

GRAV-02: Local frequency — Gaussian well (strong curvature)

Status: PASS

GRAV-03: Local frequency — Gaussian well (broader potential)

Status: PASS

GRAV-04: Local frequency — Gaussian well (shallow potential)

Status: PASS

GRAV-05: Local frequency — linear χ-gradient (moderate)

Status: PASS

GRAV-06: Local frequency — Gaussian well (stable reference)

Status: PASS

GRAV-07: Time dilation — bound states in double-well potential (KNOWN: Packet becomes trapped, demonstrates bound state physics) (Skipped: Exploratory: bound-state measurement pending; packet trapping)

Status: SKIP

GRAV-08: Time dilation — uniform χ diagnostic (isolate grid dispersion)

Status: PASS

GRAV-10: Gravitational redshift — measure frequency shift in 1D potential well

Status: PASS

GRAV-11: Time delay — packet through χ slab (Shapiro-like) (NEEDS DEBUG: Packet tracking measurement issues) (Skipped: Packet tracking diagnostics WIP; Shapiro-like delay measurement)

Status: SKIP

GRAV-12: Phase delay — continuous wave through χ slab (DEMONSTRATES: Klein-Gordon phase/group velocity mismatch - testable prediction!)

Status: PASS

GRAV-13: Local frequency — double well (ω∝χ verification)

Status: PASS

GRAV-14: Group delay — differential timing with vs without slab (NEEDS DEBUG: Signal too weak to measure delay) (Skipped: Signal too weak for robust differential timing with current setup)

Status: SKIP

GRAV-15: 3D radial energy dispersion visualizer — central excitation, volumetric snapshots for MP4

Status: PASS

GRAV-16: 3D double-slit interference — quantum wave through slits showing χ-field localization

Status: PASS

GRAV-17: Gravitational redshift — frequency shift climbing out of χ-well

Status: PASS

GRAV-18: Gravitational redshift — linear gradient (Pound-Rebka analogue)

Status: PASS

GRAV-19: Gravitational redshift — radial χ-profile (Schwarzschild analogue)

Status: PASS

GRAV-20: Self-consistent chi from E-energy (Poisson) - verify omega~=chi at center (1D)

Status: PASS

GRAV-21: GR calibration - redshift to G_eff mapping (weak-field limit)

Status: PASS

GRAV-22: GR calibration - Shapiro delay correspondence (group velocity through slab)

Status: PASS

GRAV-23: Dynamic χ-field evolution — full wave equation $\Box\chi=-4\pi G\rho$ with causal propagation (gravitational wave analogue)

Status: PASS

GRAV-24: Gravitational wave propagation — oscillating source radiates χ-waves, validate 1/r decay and propagation speed

Status: PASS

GRAV-25: Light bending — ray tracing through χ-gradient, measure deflection angle

Status: PASS

Tier 3 — Energy Conservation (Hamiltonian partitioning, dissipation)

ENER-01: Global conservation — short

Status: PASS

ENER-02: Global conservation — long

Status: PASS

ENER-03: Wave integrity — mild curvature

Status: PASS

ENER-04: Wave integrity — steep curvature

Status: PASS

ENER-05: Hamiltonian partitioning — uniform χ (KE ↔ GE flow)

Status: PASS

ENER-06: Hamiltonian partitioning — with mass term (KE ↔ GE ↔ PE flow)

Status: PASS

ENER-07: Hamiltonian partitioning — χ-gradient field (energy flow in curved spacetime)

Status: PASS

ENER-08: Dissipation — weak damping (exponential decay, γ=1e-3 per unit time)

Status: PASS

ENER-09: Dissipation — strong damping (exponential decay, γ=1e-2 per unit time)

Status: PASS

ENER-10: Thermalization — noise + damping reaches steady state

Status: PASS

Tier 4 — Quantization (Discrete exchange, spectral linearity, uncertainty)

QUAN-01: ΔE Transfer — Low Energy

Status: PASS

QUAN-02: ΔE Transfer — High Energy

Status: PASS

QUAN-03: Spectral Linearity — Coarse Steps

Status: PASS

QUAN-04: Spectral Linearity — Fine Steps

Status: PASS

QUAN-05: Phase-Amplitude Coupling — Low Noise

Status: PASS

QUAN-06: Phase-Amplitude Coupling — High Noise

Status: PASS

QUAN-07: Nonlinear Wavefront Stability

Status: PASS

QUAN-08: High-Energy Lattice Blowout Test

Status: PASS

QUAN-09: Heisenberg uncertainty — $\Delta x \cdot \Delta k \approx 1/2$

Status: PASS

QUAN-10: Bound state quantization — discrete energy eigenvalues E_n emerge from boundary conditions

Status: PASS

QUAN-11: Zero-point energy — ground state $E_0 = \frac{1}{2}\hbar\omega \neq 0$ (vacuum fluctuations)

Status: PASS

QUAN-12: Quantum tunneling — barrier penetration when E < V (classically forbidden)

Status: PASS

QUAN-13: Wave-particle duality — which-way information destroys interference

Status: PASS

QUAN-14: Non-thermalization — validates Klein-Gordon conserves energy (doesn't approach Planck)

Status: PASS