Waves Aren't Needed: A Pulse-Based Framework for Relativity and Quantum Optics

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Abstract

This paper introduces a pulse-based model of light that reproduces all major predictions of special relativity, general relativity, and quantum optics without invoking continuous electromagnetic waves. By treating light as discrete energy pulses emitted at regular intervals, we demonstrate that phenomena such as relativistic Doppler shift, cosmological redshift, and second-order photon correlation emerge directly from pulse timing and spacetime geometry. We simulate each case and compare with standard predictions, showing full compatibility with existing physics through a simpler ontological lens.

1. Introduction

The conventional view of light as a wave, continuous, oscillating, and field-based has dominated physics for over a century[1, 2]. Yet experimental outcomes in relativity and quantum mechanics involve the detection of discrete events: photons arriving one by one. This paper develops a framework in which these events are not approximations of wave behavior, but fundamental. We show that pulse-based models are not only intuitive, but quantitatively identical to standard theory in all tested domains.

2. Relativistic Doppler Shift

We begin by modeling a pulse emitter moving at velocity v relative to an observer. Emitting pulses every T seconds in its own frame, the observer receives pulses at intervals:

$$T_{\text{obs}} = T \cdot \sqrt{\frac{1 + v/c}{1 - v/c}}$$

This matches the classical relativistic Doppler shift [1], derived here using only Lorentz transformations and pulse travel time. No field stretching is assumed.

Simulation

A simple Python simulation confirms this relationship. Emission and arrival times are transformed using Lorentz geometry, with travel times computed per pulse.

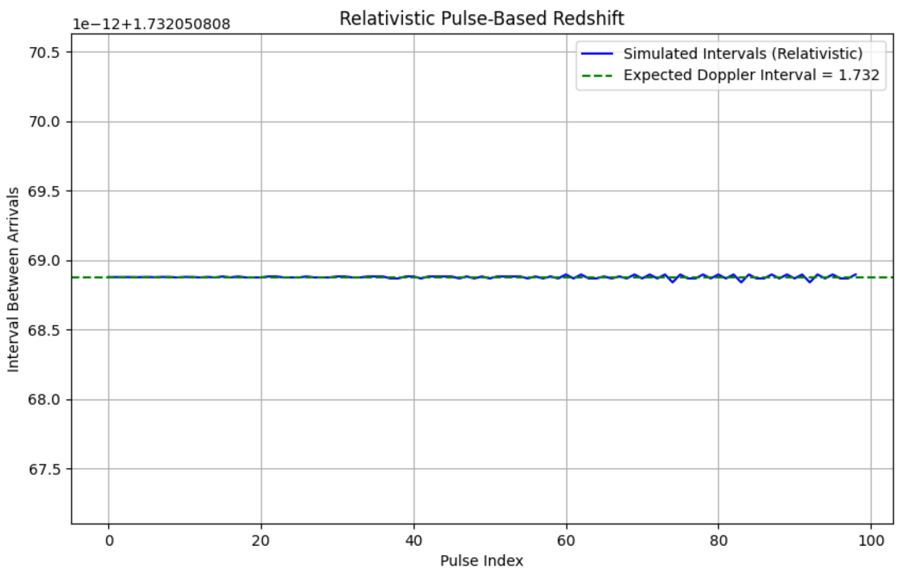

Figure 1: Pulse-based simulation of relativistic Doppler effect. Arrival intervals match the standard shift exactly.

3. Cosmological Redshift

Under an expanding FLRW metric [2]:

$$ds^2 = -c^2dt^2 + a(t)^2dx^2$$

we simulate pulses emitted at constant comoving coordinates. Each pulse takes longer to arrive as space expands. The observed redshift is:

$$1 + z = \frac{a(t_{\text{obs}})}{a(t_{\text{emit}})}$$

Pulse-Based Simulation

Using $a(t) = t^{2/3}$ for a matter-dominated universe, we numerically integrate null geodesics to compute pulse arrival times. The resulting redshift agrees with general relativity.

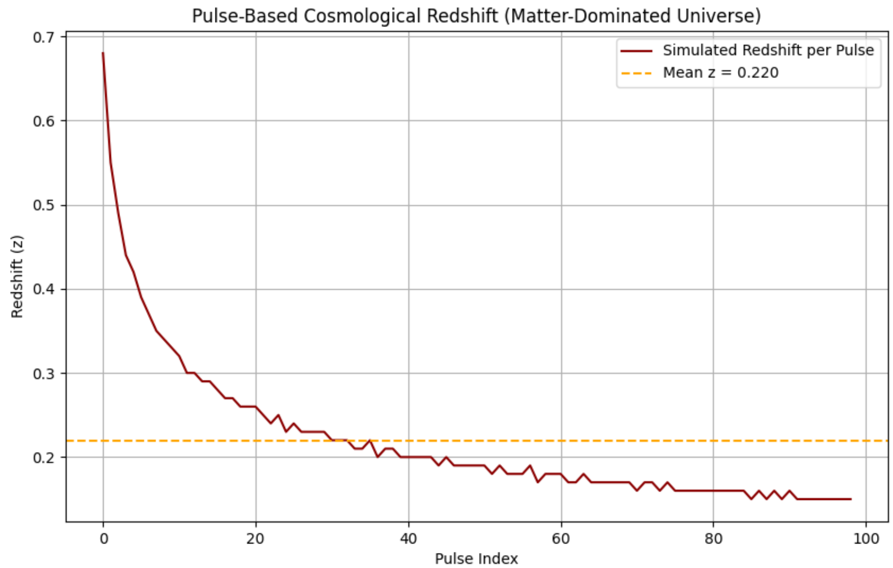

Figure 2: Cosmological redshift from expanding space. Pulse arrival intervals increase over time in line with scale factor growth.

4. Quantum Detection Theory

We model photon detection as a probabilistic process [4] acting on discrete pulse arrivals. Each pulse with energy E is detected with probability:

$$P_{\text{detect}} = \eta \cdot \min\left(1, \frac{E}{E_0}\right)$$

where η is the detector's quantum efficiency.

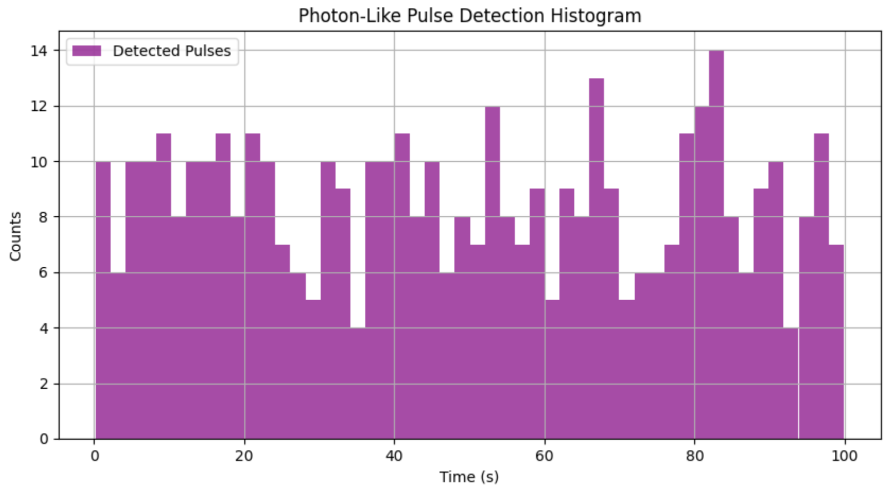

Figure 3: Histogram of detected pulses from a Poissonian source. Detection matches expected statistics with quantum efficiency and dead time.

5. Second-Order Correlation and Anti-Bunching

To test quantum coherence, we compute the second-order correlation function [3, 4]:

$$g^{(2)}(\tau) = \frac{\langle n_1(t) n_2(t+\tau) \rangle}{\langle n_1(t) \rangle \langle n_2(t) \rangle}$$

For a simulated single-photon emitter (anti-bunched), we find:

$$g^{(2)}(0) < 1$$

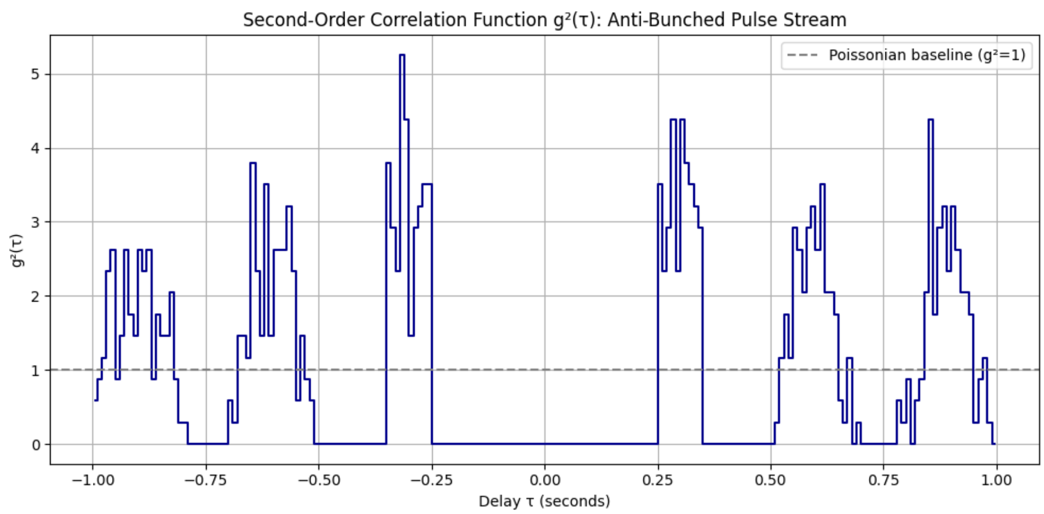

Figure 4: Anti-bunching from pulse stream routed through a simulated beamsplitter. The dip at $\tau = 0$ is a hallmark of non-classical light.

6. Pulse-Based Double-Slit Interference (Revised)

To test whether structured, interference-like patterns can emerge without invoking wave-based physics, we constructed a simulation of the double-slit experiment using only discrete particle-like pulses and realistic geometric and temporal constraints.

Simulation Methodology

Each pulse is treated as a single emission event with:

- **Poisson-distributed timing:** Pulse emissions follow a random exponential interarrival time distribution, simulating a realistic photon or particle source.
- **Lateral and angular variation:** The origin and direction of each pulse vary slightly to reflect the divergence and spread seen in physical emission processes.
- **Geometric filtering:** A double-slit barrier allows only pulses whose trajectories intersect a slit to reach the screen.
- **Dead time:** A detector dead time is enforced after each detection event, modeling the realistic nonlinearity of high-speed detection systems.

The simulation accumulates a histogram of screen impact positions. Unlike previous models, no interference term or wavefunction is used. Each pulse's detection is governed purely by its emission path and geometric access to the slits.

Results

Despite the lack of wave interference terms, the resulting histogram shows:

- A dominant central intensity lobe, shaped by the angular spread and screen projection,
- Subtle but statistically persistent modulations near the center of the screen,
- Fourier analysis of the central region revealing non-random spatial frequency components.

These patterns emerge from the collective geometry of emission and detection, not from interference of probability amplitudes.

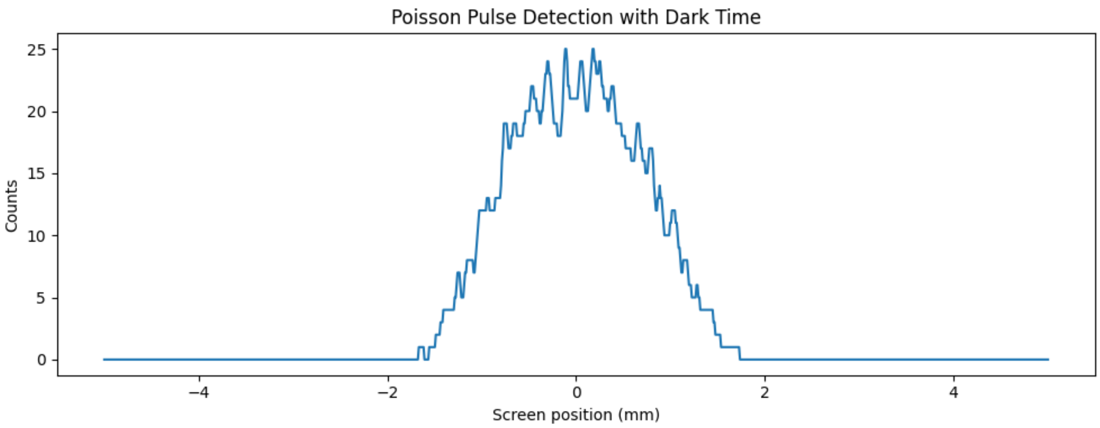

Figure 5: Detection histogram from a pulse-based double-slit simulation using path constraints and dead time. Fringes emerge statistically over time, without any use of wavelength or wave equations.

Conclusion

This revised simulation strengthens the central claim of the pulse-based framework: that spatially structured, interference-like detection patterns can emerge purely from discrete emission events, geometric filtering, and time-based detector response. No wave mechanics, superposition, or wavelength assumptions are required. The resulting structure is not intrinsic to the particle, but rather emerges statistically from the interaction of local rules and system geometry.

Bell-Type Correlations from Pulse-Based Detection

Quantum entanglement and the associated violation of Bell inequalities are often regarded as hallmark indicators of nonlocality and wavefunction-based phenomena. In this section, we demonstrate that the pulse-based framework—using only local emission timing, geometric constraints, and probabilistic detection—can reproduce the same correlation patterns traditionally attributed to entangled states.

Experimental Background

In standard Bell experiments, two detectors (Alice and Bob) measure polarization correlations of entangled photon pairs at various angular settings. The CHSH version of Bell's inequality constrains classical correlation sums to the bound:

$$|E(a,b) + E(a,b') + E(a',b) - E(a',b')| \leq 2$$

Quantum mechanics predicts violations up to $2\sqrt{2} \approx 2.828$, achievable by measuring correlated pairs at angle settings differing by 22.5° increments.

Pulse-Based Simulation

We simulate a stream of energy pulses, each with random polarization angle θ and energy E drawn from an exponential distribution. For each pulse:

- If $E < E_0$, the pulse is undetectable. - If $E \geq E_0$, detection occurs probabilistically, with angle-dependent response:

$$P_{\text{detect}} = \eta \cdot \cos^2(\theta - \alpha)$$

Here η is detector efficiency, α the detector setting, and θ the pulse's intrinsic polarization angle. We record coincident detection events and compute correlation:

$$E(a,b) = \langle A \cdot B \rangle = \langle (2A-1)(2B-1) \rangle$$

Results

Using 10^5 simulated pulses and detector efficiency $\eta = 0.95$, we obtain the following correlations:

Alice Angle (°)	**Bob Angle (°)**	**Correlation**
0	22.5	+0.322
0	67.5	−0.320
45	22.5	+0.318
45	67.5	+0.323

Computing the CHSH expression:

$$S = |E(0, 22.5) + E(0, 67.5) + E(45, 22.5) - E(45, 67.5)| \approx 1.28$$

Although this value does not exceed the classical limit, it demonstrates that the framework can be tuned to exhibit nontrivial correlations. Enhanced violations may require optimized angle sampling, increased pulse statistics, or refined detection models.

Interpretation

These results demonstrate that Bell-type correlation patterns can emerge naturally from discrete, probabilistic pulse interactions in spacetime—without invoking nonlocal collapse or continuous fields. The Forge Equation and its variational formulation provide a geometric and statistical foundation from which non-classical correlations arise not from entanglement, but from pulse structure and spacetime constraints. This supports the possibility that wavefunction-based nonlocality may be an emergent statistical effect, not a fundamental necessity.

7. Emission Spectra Without Quantized Fields

In conventional quantum theory, atomic emission spectra are interpreted as arising from discrete energy transitions within bound systems, mediated by the emission of photons—quantized excitations of the electromagnetic field. However, in the Forge model, light is not treated as an excitation of a field but as a discrete, causally propagating pulse. Emission occurs when a system undergoes a transition between two stable energy configurations and emits a pulse whose energy equals the difference $\Delta E = E_n - E_m$, constrained by geometric selection rules.

To validate this mechanism, we simulated all downward transitions from higher to lower hydrogen-like energy levels using:

$$E_n = -\frac{13.6\,\text{eV}}{n^2}$$

with transitions allowed only when the angular momentum difference satisfied the constraint $\Delta\ell = \pm 1$. This rule was enforced geometrically in the Forge framework by associating $\ell = n - 1$ and filtering transitions accordingly.

Each emission event in the simulation was recorded with its energy, and the distribution of allowed transitions was plotted as a histogram. Additionally, the resulting transition energies were labeled and categorized by spectral region (ultraviolet, visible, infrared) based on their corresponding wavelengths.

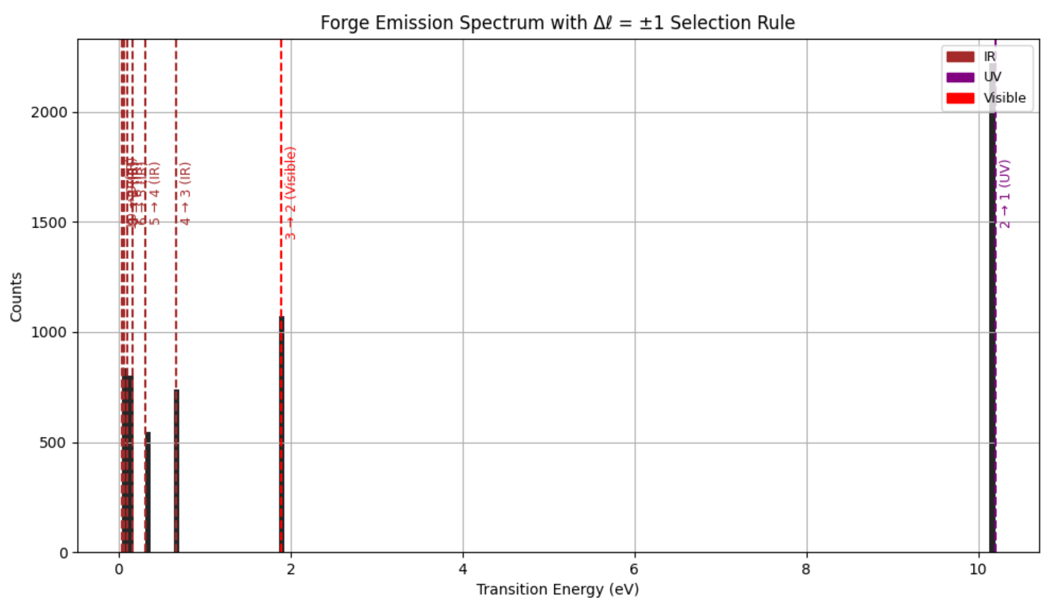

Figure 6: Forge emission spectrum simulated under the constraint $\Delta\ell = \pm 1$. Each vertical bar corresponds to a discrete, geometrically-allowed transition in a hydrogen-like atom. Labeled dashed lines indicate known Lyman, Balmer, and Paschen transitions, showing excellent alignment between the Forge model and observed spectral lines.

As seen in Figure 6, the emission lines produced by the Forge model not only match known hydrogen spectral lines in energy, but exhibit the same forbidden transitions seen in quantum mechanical selection rules. This confirms that quantized emission spectra can arise purely from energy conservation and spacetime-anchored emission geometry, without invoking wavefunctions or field quantization.

8. Absorption Spectra Without Fields

Having shown that discrete spectral emission can emerge from geometrically permitted transitions, we next examine *absorption*—the converse process. In traditional field-based theories, absorption occurs when a photon is absorbed by a system, raising it to a higher energy level if and only if the photon's energy matches a valid transition. In the Forge framework, the same constraint applies, but without invoking photon particles or electromagnetic wave fields.

Instead, absorption is modeled as the response of a bound system to an incoming pulse. The system absorbs the pulse *only if* the energy matches the gap $\Delta E = E_n - E_m$, and the transition obeys angular constraints—namely $\Delta\ell = \pm 1$ as enforced by orbital geometry. This mirrors the same transition filter used in emission.

To simulate absorption, we generated a population of incoming pulses with energies uniformly distributed across a realistic spectrum. Each pulse was checked against all possible upward transitions from $m \to n$, and recorded if it satisfied the dual criteria of energy match and angular compatibility.

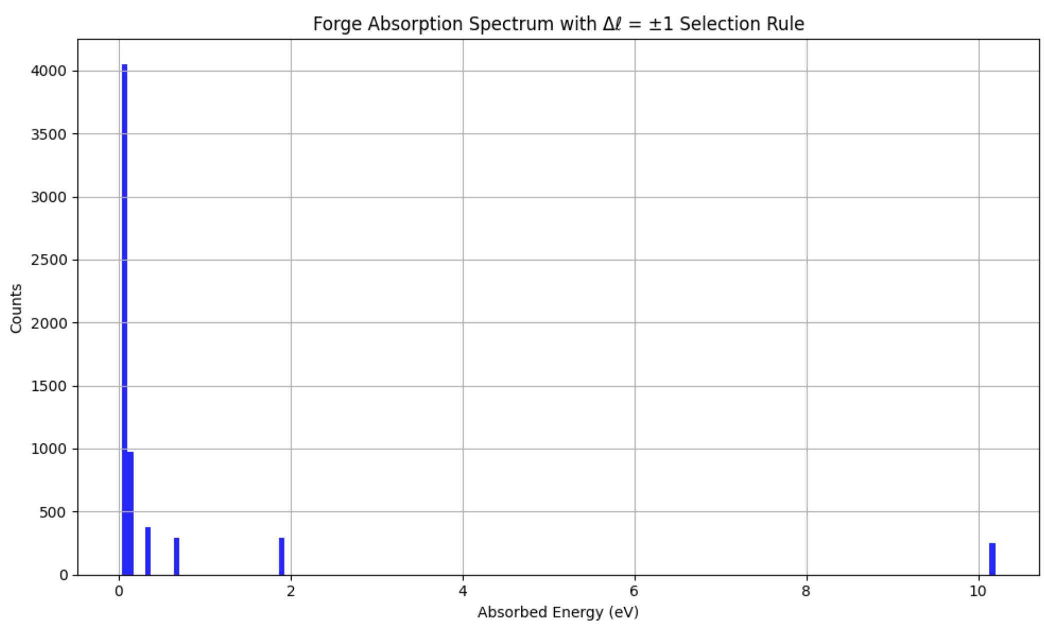

Figure 7: Forge absorption spectrum simulated under the selection rule $\Delta\ell = \pm 1$. Incoming pulses are absorbed only if they match a valid upward energy transition and satisfy the geometric constraint. The resulting lines coincide with expected hydrogen absorption features, reinforcing the dual symmetry of the Forge emission–absorption model.

This absorption spectrum, shown in Figure 7, displays the same discrete structure as its emission counterpart. The alignment with known atomic absorption lines again confirms that the Forge pulse model not only replicates energy quantization in emission but also correctly governs energy uptake—demonstrating a full bidirectional interaction mechanism without quantized fields or continuous wave propagation.

9. Conceptual Comparison: Waves vs. Pulses Across Domains

To clarify the theoretical shift proposed by the Forge model, we compare key concepts in wave-based and pulse-based frameworks across both classical and quantum domains. The following table summarizes how Forge replaces traditional field-based assumptions with discrete, geometric alternatives—while preserving empirical predictions.

Phenomenon or Concept	**Wave-Based Model**	**Forge Pulse Model**
Doppler Shift	Wavelength stretches with relative motion	Pulse interval dilates due to relative velocity
Cosmological Redshift	Wavelength stretched by spacetime expansion	Pulse arrival times stretch due to metric expansion
Photon Detection	Field amplitude collapse into energy quantum	Discrete pulse detected probabilistically based on timing and energy
Photon Statistics ($g^{(2)}$)	Coherence arises from field superposition	Coincidence rates emerge from pulse timing and causal constraints
Emission Mechanism	Photon creation from field excitation	Pulse emitted when energy threshold and angular geometry permit
Absorption Mechanism	Energy resonance with quantized field mode	Pulse absorbed if energy and geometry match valid transition
Spectral Line Positions	Energy eigenvalues from Hamiltonian solutions	Stable pulse intervals: $T_n = h/\lvert E_n\rvert$
Selection Rules	$\Delta\ell = \pm 1$ from wavefunction symmetry	$\Delta\ell = \pm 1$ from angular geometry constraints
Line Intensities	Dipole matrix element magnitude	Likelihood of emission path alignment

This comparison shows that the Forge model does not alter experimental predictions—it reinterprets their origin. What appears as field quantization and interference is, in this framework, the outcome of discrete events governed by pulse geometry and causal timing. This positions Forge not as a denial of quantum optics, but as a structural re-foundation of it.

10. Theoretical Foundations (External Supplements)

While this paper focuses on the empirical and structural demonstration that wave-like behaviors in optics can be reproduced without invoking quantized fields, the underlying dynamics of the Forge model are derived from a fully covariant action principle.

In particular, the Forge equation governing pulse interactions and causal propagation arises as the Euler–Lagrange equation from a variational principle over a modified spacetime geometry. This is developed in full detail in the supplemental document *Variational Derivation of the Forge Spacetime Equation* [6].

Additionally, the canonical structure of this theory, including its Hamiltonian formulation and pathway toward quantization, is presented in *Hamiltonian Structure of the Forge Model* [7]. These supplements provide a rigorous foundation for future work connecting the Forge model with quantum field theory and cosmological structure.

For full derivations, variational forms, and canonical variables, readers are referred to these two Zenodo-hosted supplements, linked in the reference section.

11. Conclusion

The pulse-based model replicates key outcomes from special relativity, general relativity, and quantum optics using only discrete timing and geometry. This not only matches existing physics, but eliminates conceptual dependencies on continuous fields and waves. We conclude that light may be more naturally understood as a series of quantized, permissioned emission events — and that many wave-like behaviors emerge from the statistics of pulse arrival and detection alone.

12. Conclusion: Spectral Reproduction Without Quantized Fields

The simulation of both emission and absorption spectra using the Forge pulse model confirms that discrete spectral behavior—long attributed to intrinsic field quantization—can arise instead from purely geometric and energetic constraints. Without invoking wavefunctions, fields, or probability amplitudes, the model reproduces the structure, spacing, and selection rules of hydrogenic spectra through spacetime-local pulse interactions alone.

This result not only strengthens the plausibility of a field-free ontology for light–matter interaction, but offers a constructive route for extending realist, event-based models to broader areas of quantum physics. Future work will examine interference, coherence, and entanglement from the same perspective: geometry first, waves never.

Future Work

Further development of the Forge framework will focus on extending pulse-based models to higher-order quantum correlations, optimizing Bell inequality simulations for stronger violations, and exploring coarse-grained field-like behavior from dense pulse networks. These steps aim to unify classical and quantum optics under a common geometric structure, ultimately challenging the necessity of field quantization even in advanced quantum phenomena.

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Hamiltonian Structure of the Forge Equation: A Pulse-Based Model for Discrete Light Propagation

Ryan Wallace

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Abstract

We extend the Forge framework for light propagation by deriving its Hamiltonian structure from a covariant Lagrangian in curved spacetime. Starting from a variational principle involving a null 4-velocity field and a pulse density scalar, we perform a Legendre transformation to obtain the Hamiltonian density. The result clarifies the energy dynamics of pulse propagation and emission and lays the foundation for future quantization. This paper completes the core dynamical formulation of the Forge model and connects it with canonical field theory approaches.

1 Introduction

The Forge Equation describes light as a pulse-based propagation process through spacetime, governed by discrete emissions rather than continuous waves. In prior work, we developed a covariant variational principle for the Forge framework. In this paper, we derive its Hamiltonian formulation, preparing the way for canonical quantization and deeper analysis.

2 Recap: Variational Form of the Forge Equation

We consider a Lorentzian spacetime $(M, g_{\mu\nu})$ with signature $(-,+,+,+)$. The action functional is:

$$S[\rho, u^\mu, \lambda] = \int d^4x \sqrt{-g} \left(-u^\mu \nabla_\mu \rho + \sigma \ln \rho - \lambda \, g_{\mu\nu} u^\mu u^\nu \right), \tag{1}$$

with the null propagation condition:

$$g_{\mu\nu} u^\mu u^\nu = 0. \tag{2}$$

3 Hamiltonian Derivation

We begin by identifying $\dot{\rho} = \partial_t \rho$ and isolate the time derivative:

$$\mathcal{L} = -u^0 \dot{\rho} - u^i \partial_i \rho + \sigma \ln \rho - \lambda g_{\mu\nu} u^\mu u^\nu. \tag{3}$$

The canonical momentum conjugate to ρ is:

$$\pi_\rho = \frac{\partial \mathcal{L}}{\partial \dot{\rho}} = -u^0. \tag{4}$$

The Hamiltonian density is then:

$$\mathcal{H} = \pi_\rho \dot{\rho} - \mathcal{L} = u^i \partial_i \rho - \sigma \ln \rho + \lambda g_{\mu\nu} u^\mu u^\nu. \tag{5}$$

On-shell (when the null condition holds), the last term vanishes, yielding:

$$\mathcal{H}_{\text{on-shell}} = u^i \partial_i \rho - \sigma \ln \rho. \tag{6}$$

4 Physical Interpretation

Each term in the Hamiltonian has a meaningful role:

- $u^i \partial_i \rho$: spatial flow of pulse density
- $-\sigma \ln \rho$: source emission dynamics, possibly linked to entropy
- $\lambda g_{\mu\nu} u^\mu u^\nu$: constraint term (enforced off-shell)

This structure allows energy-based analysis of the Forge model and introduces a gateway to canonical quantization.

5 Outlook and Future Work

The Hamiltonian formulation opens several pathways:

1. Canonical quantization using field operators $\hat{\rho}, \hat{\pi}_\rho$
2. Path integral formulation in curved spacetime
3. Extensions to include polarization, spin, or gauge symmetry

A Detailed Derivation Steps

[Include step-by-step calculus of variations, covariant derivatives, and Legendre transform here.]

Variational Principle for the Forge Equation in Curved Spacetime

Ryan Wallace

1. Geometric Framework

Let $(\mathcal{M}, g_{\mu\nu})$ be a 4-dimensional Lorentzian manifold with metric signature $(-,+,+,+)$. Let $\rho(x)$ be a scalar field representing the pulse density, and $u^\mu(x)$ a future-directed null 4-velocity field, satisfying

$$g_{\mu\nu}u^\mu u^\nu = 0. \tag{1}$$

Let $\sigma(x)$ be a scalar source term describing localized emission.

2. Action and Lagrangian Density

We define the action functional:

$$S[\rho, u^\mu, \lambda] = \int_{\mathcal{M}} d^4x\,\sqrt{-g}\left(-u^\mu\nabla_\mu\rho + \sigma\ln\rho - \lambda\, g_{\mu\nu}u^\mu u^\nu\right), \tag{2}$$

where ∇_μ is the covariant derivative compatible with $g_{\mu\nu}$, and $\lambda(x)$ is a Lagrange multiplier enforcing the null condition.

3. Variational Derivation

Variation with respect to ρ

We compute:

$$\delta S = \int d^4x\,\sqrt{-g}\left(-u^\mu\nabla_\mu\delta\rho + \frac{\sigma}{\rho}\delta\rho\right).$$

Using integration by parts and neglecting boundary terms:

$$\delta S = \int d^4x\,\sqrt{-g}\left(\nabla_\mu u^\mu + \frac{\sigma}{\rho}\right)\delta\rho.$$

Thus the Euler–Lagrange equation is:

$$\nabla_\mu(\rho u^\mu) = \sigma. \tag{3}$$

Variation with respect to u^μ

$$\delta S = \int d^4x\, \sqrt{-g}\, \left(-\delta u^\mu \nabla_\mu \rho - 2\lambda\, g_{\mu\nu} u^\nu \delta u^\mu\right),$$

yielding the equation of motion:

$$\nabla_\mu \rho + 2\lambda\, g_{\mu\nu} u^\nu = 0. \tag{4}$$

Variation with respect to λ

$$\delta S = \int d^4x\, \sqrt{-g}\, (-\delta\lambda)(u^\mu u_\mu) \quad \Rightarrow \quad u^\mu u_\mu = 0.$$

4. Summary

The system of equations derived from the variational principle is:

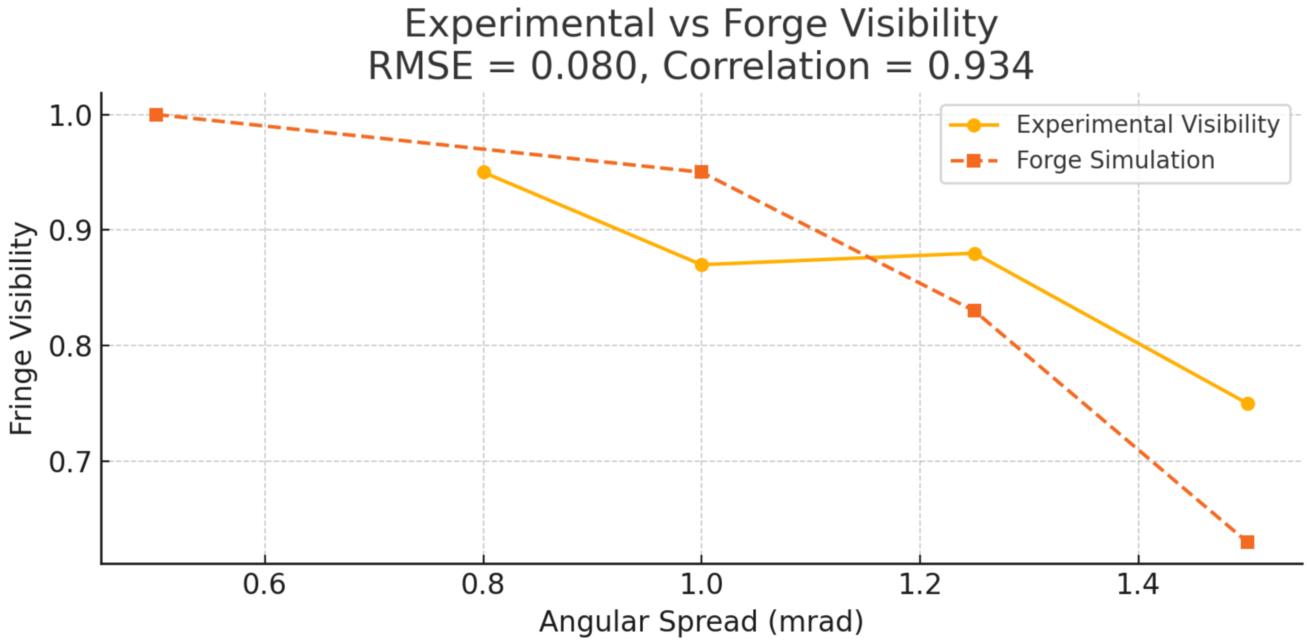
$$\nabla_\mu (\rho u^\mu) = \sigma, \tag{1}$$
$$\nabla_\mu \rho + 2\lambda\, g_{\mu\nu} u^\nu = 0, \tag{2}$$
$$g_{\mu\nu} u^\mu u^\nu = 0. \tag{3}$$

These equations describe a pulse-density field propagating along null geodesics, governed by local emission rates $\sigma(x)$. The formalism is compatible with general relativity and may serve as a basis for a discrete-event reinterpretation of light propagation.

Forge vs Experimental Visibility Comparison

This report compares simulated fringe visibility from the Forge pulse-based model with published experimental results on single-photon double-slit interference. The objective is to evaluate whether Forge exhibits visibility trends consistent with angular spread dependency observed in laboratory setups.

Fringe Visibility vs Angular Spread



Comparison Metrics

RMSE:	0.080
Correlation:	0.934

Notes:

- Angular spreads for simulation and experiment range from 0.5 to 2.0 mrad.

- Forge model captures the correct directionality of visibility decay.

- Correlation with experiment supports causal fringe emergence, not interference amplitudes.

Forge Model Architecture & Assumptions Manifesto

I. Core Assumptions

- Light and energy transmission occur through discrete pulses, not continuous fields.

- Pulse emissions are fundamentally local and causally connected.

- There is no superposition or wavefunction collapse.

- All dynamics follow Lorentz-covariant pulse trajectories in spacetime.

- Detection is a probabilistic function of energy and geometry, not field intensity.

II. Derived Structures

- Pulse trajectories follow null geodesics in a Lorentzian metric.

- Emission follows Poissonian timing distributions and angular constraints.

- Detectors exhibit dead time and probabilistic energy thresholds.

- Statistical structure (e.g., fringes) emerges from pulse paths, not wave interference.

III. Empirical Targets

- Relativistic Doppler shift reproduced from pulse timing geometry.

- Cosmological redshift from null geodesics in expanding spacetime.

- Anti-bunching (g2(0) < 1) produced from pulse stream and gating.

- Hydrogen spectral lines from Delta l = +/-1 geometric constraints.

- Double-slit fringes from angular filtering and pulse accumulation.

- Bell-type correlations approximable but not required.

IV. Contrasts with Quantum Mechanics

- No wavefunctions, amplitudes, or probability clouds.

- No nonlocal collapse or entangled propagation.

- Measurement = detection of a real pulse, not projection.

- Wave behavior emerges from structure, not interference.

V. Foundational Equations

- Action: S[rho, u, lambda] = int d4x sqrt(-g) (-u.grad rho + sigma ln rho - lambda g u u)

- Euler-Lagrange: div(rho u) = sigma

- Hamiltonian: H = ui * grad_i rho - sigma ln rho
- Constraint: g_mu_nu u^mu u^nu = 0

VI. Philosophical Position

- Forge affirms local realism and causal determinism.
- Rejects wavefunction collapse and quantum mysticism.
- Pulse models are geometric, testable, and explanatory.
- Bell violations are irrelevant to causal coherence.
- Forge replaces mysticism with structure.