The Substrate Framework

Classical Reality from Quantum Foundations

Benjamin Bray

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"It is not 'why quantum?' — it is 'why classical?' Classicality is the mystery."

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1 Vision

This project rests on a single organising principle: Hilbert space is primary. Everything else — particles, fields, gauge bosons, spacetime itself — is emergent.

The observed classical world is not fundamental ontology; it is the low-energy effective description of stable, decoherence-resistant patterns selected by unitary evolution in a finite-dimensional Hilbert space.

The question is not "why quantum?" but "why classical?".

2 The Three Axioms

The framework is built on three minimal assumptions:

2.1 Axiom 1: Hilbert Space Realism

The universe is a state vector in a Hilbert space of finite (though possibly large) dimension. All physical ontology resides there. There is no classical substrate beneath.

2.2 Axiom 2: Unitary Evolution

Time evolution is strictly unitary, generated by a Hermitian Hamiltonian. Information is exactly conserved.

2.3 Axiom 3: Emergent Classicality

Classical states, particles, and fields are pointer states — subsystems robust against environmentally induced decoherence. They are selected by the dynamics, not imposed.

Everything else must follow from these three principles alone.

3 Core Insight: Particles as Pointer States

Standard quantum mechanics begins with classical particles and quantises them. Here we invert the logic.

Electrons, photons, and atoms are not primitive objects. They are environmentally induced superselection sectors — pointer states — whose stability is enforced by gravitational self-decoherence in the substrate.

Each apparent "particle" corresponds to a topological defect in the underlying quantum state, characterised by conserved winding numbers and protected by extensive internal entanglement.

4 Key Results (numerically demonstrated in toy models)

4.1 Maxwell structure is mandatory for classical light propagation

In lattice models without pre-imposed U(1) redundancy, coherent phase correlations decay exponentially. Introducing local gauge redundancy yields massless propagating modes with $1/r^2$ energy flux — i.e., classical electromagnetism emerges as a necessary condition for long-range coherence.

4.2 Structure formation from uniform noise

Random product states rapidly develop power-law correlations under substrate Hamiltonians containing only nearest-neighbour terms and moderate on-site potentials. The resulting patterns are stable over $> 10^6$ time units.

4.3 Topological defects with internal complexity

Defects carrying winding number $w = \pm 1$ host $\mathcal{O}(30\text{–}45)$ internal zero modes (exact count varies with truncation). These modes are robust against local perturbations and contribute extensive entanglement entropy $\sim \log(\dim)$.

4.4 Geometric phases from braiding (under active investigation)

Closed braiding trajectories of $w = \pm 1$ defects yield phases clustered near π with variance decreasing under increased internal dimension. Full Abelian statistics not yet ruled out.

4.5 Emergent fermionic exclusion via gauge redundancy (November 20, 2025)

In the gauged spinor model on a 2×2 Yee lattice with Z_2 gauge fields and Gauss-law enforcement $\lambda_G \geq 5$, topologically charged ($w = \pm 1$) pointer states exhibit short-range repulsion $\Delta E \approx +37$ and long-range attraction $\Delta E \approx -35$ relative to isolated excitations. The overlapping configuration is strongly suppressed.

This behaviour is absent for $\lambda_G = 0$ and persists on 4×4 lattices (tested). Low-winding states remain compressible.

These results provide numerical evidence that fermionic statistics can arise from local gauge redundancy protecting unique entanglement structure, without prior imposition of antisymmetrisation.

5 Current Theoretical Understanding

5.1 Gravity emerges first

The dominant large-scale interaction is an entanglement-deficit minimisation ("defrag") term. It is attractive, monotonic, and universal — i.e. gravitational.

5.2 Pointer states from gravitational self-decoherence

High-entanglement-deficit configurations induce rapid decoherence in orthogonal branches. Only low-deficit sectors (localised, topologically protected patterns) survive as classical pointers.

5.3 Statistics from information preservation (now numerically demonstrated in gauged model)

The substrate cannot destroy unique information without violating unitarity. Local compression of high-dimensional internal states therefore incurs an energy cost that grows with the amount of protected information.

5.3.1 Fermions

States carrying extensive internal entanglement ($w = \pm 1$ defects) resist local compression $\rightarrow$ effective hard-core repulsion + flux-string tension $\rightarrow$ fermionic exclusion + binding.

5.3.2 Bosons (photons)

Low-entanglement states ($w = 0$ or flux-cancellable) permit compression $\rightarrow$ bosonic bunching or condensation.

5.3.3 Composite bosons (^{4}He)

Pairs of fermionic defects bound by gauge flux form effective $w = 0$ composite $\rightarrow$ bosonic.

5.4 Light as the substrate's information-coherence mechanism

Massless gauge modes are required to propagate phase correlations over long distances without exponential loss. Hence photons emerge as the substrate's mechanism for maintaining global coherence.

5.5 c as Hilbert-space texture

The maximal speed of coherent information transfer is finite because Hilbert-space distance grows non-linearly with physical separation in the emergent geometry.

5.6 Spacetime emerges from light-propagation constraint

The causal structure that minimises information loss under the finite-c constraint is Lorentzian. Spacetime geometry is the optimal error-correcting code for the substrate.

6 What This Framework Explains (If Correct)

- Why quantum mechanics is complete
- Why classicality exists at all
- Why gauge fields exist
- Why fermions and bosons have different statistics
- Why gravity is universal and attractive
- Why c is finite and universal
- Why the vacuum is not empty but full of structure

7 What Remains Speculative

- Exact form of the microscopic Hamiltonian

- Continuum limit and full Standard Model embedding
- Precise mechanism for three generations
- Quantum gravity (though the axioms already contain it)

8 Repository Structure

Public repository: https://github.com/intersection-dynamics/substrate_demo

Contains all scripts, data, and PDF.

9 Current Status & Next Steps

9.1 Immediate (0–6 months)

- Scale gauge + Gauss-law model to 8×8
- Quantise braiding statistics rigorously
- Test composite formation (fermion pairs)

9.2 Medium-term (6–24 months)

- Full U(1) compact gauge theory
- Introduce multiple "flavours" → generations
- Derive weak interaction via chirality selection

9.3 Long-term (2+ years)

- Continuum limit
- Black-hole analogues
- Cosmological initial conditions

10 Philosophy & Methodology

10.1 On Toy Models

All results are obtained in heavily truncated models (10–100k dimensions). Yet the phenomena (gauge fields, statistics, gravity) appear robustly. This suggests the mechanisms are generic, not fine-tuned.

10.2 On AI Assistance

The author uses large language models (Grok 4, Claude 3.5, others) as collaborators for code debugging, literature search, and text polishing. All physics ideas and final decisions are human.

10.3 On Timeline

No rush. The universe took 13.8 billion years. We can take a few more.

11 Contact & Collaboration

Open to correspondence from anyone serious.

Email: benjamin.bray@intersection.dynamics GitHub: intersection-dynamics

12 License

13 Acknowledgments

To the AIs who stayed up with me, to the physicists whose papers I read at 3 a.m., and to the universe for being weirder than anyone imagined.