Falsifiable Experimental Signatures of Density Field Dynamics: Phase Velocity Equals One-Way Light Speed in a Nondispersive Vacuum

Gary Alcock[1]

[1] *Density Field Dynamics Research Collaboration*

(Dated: August 25, 2025)

We convert *Density Field Dynamics* (DFD) into a laboratory-focused, falsifiable test program. DFD posits a single scalar field $\psi(\mathbf{x})$ that governs matter dynamics and photon propagation through a universal, *nondispersive* vacuum refractive structure. The core operational result is that, when dispersion is bounded in-band, the electromagnetic phase velocity is the one-way speed of light; hence precision phase metrology becomes a direct, synchronization-free probe of $c_1(\mathbf{x})$. We derive this identity along two independent routes (Fermat/eikonal and Gordon's optical metric), demonstrate compatibility with classic tests of relativity, and design three GR-null vs DFD-signal protocols—most decisively a co-located cavity–atom frequency ratio measured at two altitudes—with quantified, near-term sensitivities. We audit existing constraints, state explicit refutation criteria, and provide a comprehensive responses-to-criticisms section (simultaneity, equivalence principle, Lorentz invariance, "already ruled out", dispersion). The question is experimentally decidable with current optical metrology.

I. FROM PRINCIPLE TO PROTOCOL

Two-way light speed and Lorentz symmetry are constrained to extraordinary precision [1–4]. The *one-way* speed remains entangled with simultaneity conventions [5–7]. DFD proposes a dynamical scalar $\psi(\mathbf{x})$ that (i) fixes a universal vacuum refractive index $n = e^{\psi}$ for photons, and (ii) normalizes the Newtonian limit for matter via $\mathbf{a} = (c^2/2)\nabla\psi$. In a verified nondispersive band, geometric optics yields $v_{\text{phase}} = c/n$, which, with $n = e^{\psi}$, provides the operational bridge $c_1 = c\,e^{-\psi} = v_{\text{phase}}$. The novelty is experimental: *route-dependent*, synchronization-free observables that are GR-null but DFD-nonnull.

II. DFD DYNAMICS IN ONE PAGE

Adopt a scalar action with a single crossover scale,

$$\nabla\cdot\left[\mu\left(\frac{|\nabla\psi|}{a_\star}\right)\nabla\psi\right] = -\frac{8\pi G}{c^2}\,(\rho_m - \bar{\rho}_m), \qquad \mathbf{a} = \frac{c^2}{2}\nabla\psi, \tag{1}$$

so that ψ is fixed by matter density and yields $\psi \simeq -2\Phi/c^2$ in weak fields. Photons propagate by Fermat/optical metric (Sec. III). The weak-field normalization is chosen to reproduce GR's classic optical tests with PPN $\gamma = 1$ [1, 8]. A Sakharov-style perspective motivates induced kinetic terms from quantum fluctuations [9], but the empirical program below does not rely on specific UV details.

III. CORE IDENTITY: $v_{\text{phase}} = c_1$

A. Route I: Fermat/eikonal

Geometric optics extremizes $T[\gamma] = (1/c)\int_\gamma n(\mathbf{x})\,\mathrm{d}\ell$, giving $v_{\text{phase}} = c/n$ [8, 10, 11]. With $n = e^{\psi}$ fixed by dynamics, $c_1 = ce^{-\psi} = v_{\text{phase}}$ follows. No distant clocks enter: the observable is local phase kinematics, verified nondispersive.

B. Route II: Gordon's optical metric

Light in a linear, isotropic, nondispersive medium follows null geodesics of

$$\mathrm{d}\tilde{s}^2 = \frac{c^2}{n^2(\mathbf{x})}\,\mathrm{d}t^2 - \mathrm{d}\mathbf{x}^2 \tag{2}$$

[12]. Nullness implies $\mathrm{d}\ell/\mathrm{d}t = c/n$; with $n = e^{\psi}$ the same identity follows. The equality is therefore structural (two logically independent routes), not a definitional tautology.

IV. EQUIVALENCE PRINCIPLE & LORENTZ INVARIANCE

Local Lorentz invariance. ψ is a scalar; the light cone at a point remains isotropic. Two-way orientation/boost tests remain null at the 10^{-17}–10^{-18} level, consistent with cavity experiments [2–4].

Universality for matter. Test bodies obey $\mathbf{a} = (c^2/2)\nabla\psi$ in the weak field, reproducing free-fall universality and PPN $\gamma = 1$ optics [1]. Equivalence principle tests remain satisfied in this limit.

Where differences appear. DFD predicts *route-dependent*, synchronization-free effects where GR enforces strict nulls: e.g., a co-located cavity–atom *ratio* compared at two altitudes (Sec. VI). This is an LPI probe in a nondispersive vacuum sector not covered by atom–atom redshift verifications.

V. WHAT EXISTING TESTS DO—AND DO NOT—CONSTRAIN

Two-way isotropy & boost (Michelson–Morley/Kennedy–Thorndike; modern rotating cavities) are exquisitely null [2–4]; DFD predicts the same nulls for two-way observables along fixed paths.

Atomic clock redshift confirms GR at $\sim 10^{-16}$ per meter and below [13, 14]; spaceborne tests reach 2.5×10^{-5} relative precision [15]. These are atom–atom or remote-transfer comparisons.

Critical gap: To our knowledge, no published measurement reports a *co-located cavity–atom frequency ratio* recorded at two different gravitational potentials with $< 10^{-16}$ fractional uncertainty. That is the target of Protocol C.

VI. LABORATORY PROTOCOLS (GR-NULL VS DFD-SIGNAL)

All protocols enforce nondispersion via multi-wavelength checks which bound $|\partial n/\partial\omega|$ in the measurement band (so phase=group=front) [10, 16].

Protocol A: Crossed ultra-stable cavities (orientation/height sweep)

Two orthogonal high-Q cavities (length L) support modes $f_m \simeq \frac{m}{2L}\frac{c}{n}$. A change $\delta\psi$ imparts $\delta f/f = -\delta n/n = -\delta\psi$. Orientation reversals and vertical translations by Δh probe geometry-locked shifts. *Target sensitivity:* 10^{-17}–10^{-16} fractional, routinely achieved [2, 4].

Protocol B: Reciprocity-broken fiber loop (two heights)

A monochromatic tone circulates both ways around an asymmetric loop with vertical separation Δh and a nonreciprocal element. The accumulated phase $\phi = \frac{\omega}{c}\int n(\mathbf{x})\,\mathrm{d}\ell$ yields a forward–backward difference $\propto \oint \psi\,\mathrm{d}\ell$ that vanishes in GR (static loop, Sagnac subtracted) but not in DFD if $\nabla\psi \cdot \hat{\boldsymbol{z}} \neq 0$. Operate near a zero-dispersion wavelength; multi-λ tracking bounds dispersion [17].

Protocol C (decisive): Co-located cavity–atom ratio across altitude

Lock a laser to a vacuum cavity (frequency $f_{\rm cav} \propto c/n$) and compare to a co-located optical atomic transition $f_{\rm at}$ via a frequency comb; form $R \equiv f_{\rm cav}/f_{\rm at}$ at altitude h_1, repeat at $h_2 = h_1 + \Delta h$.

GR: Moving the *co-located* package changes neither the local ratio nor local physics; gravitational redshift appears upon comparison between distinct potentials, so R is (to excellent approximation) constant.

Protocol	Observable	DFD signal (order)
A: Crossed cavities	$\delta f/f$ on rotate/Δh	10^{-16} per m (vertical)
B: Fiber loop	$\Delta\phi_{\circlearrowright} - \Delta\phi_{\circlearrowleft}$	geometry-locked, $< 10^{-16}$ eqv.
C: Cavity/atom ratio	$\Delta R/R$ across Δh	$2g\Delta h/c^2 \approx 2.2 \times 10^{-14}$ per 100 m

TABLE I. Order-of-magnitude DFD signals in verified nondispersive band. GR predicts strict nulls for A/B and near-null for C.

DFD (nondispersive): With $\psi \simeq -2\Phi/c^2$, $f_{\rm cav} \propto e^{-\psi} \simeq 1 + 2\Phi/c^2$, while the atomic transition is leading-order ψ-insensitive (matter-sector universality). Thus

$$\frac{\Delta R}{R} \simeq 2\,\frac{\Delta\Phi}{c^2} \approx 2\,\frac{g\,\Delta h}{c^2} \sim 2.2 \times 10^{-14} \;\text{ per 100 m.} \tag{3}$$

A variant with small matter-sector coupling yields $\frac{\Delta R}{R} = \xi\,\Delta\Phi/c^2$ with $0 < \xi \leq 2$, still at the $10^{-16}\,\mathrm{m}^{-1}$ scale. *Feasibility:* present clocks and cavities reach 10^{-17}–10^{-16} [2, 4, 13, 14].

Systematics & controls (all protocols). (i) Multi-λ dispersion bound; (ii) temperature/strain control, Allan budgeting; (iii) polarization scrambles and hardware swaps; (iv) blind orientation/height reversals; (v) environmental monitors (pressure, tilt, vibration).

VII. PREDICTED SIGNAL SIZES AND SENSITIVITY TABLE

VIII. REFUTATION CRITERIA (CLEAN KILL CONDITIONS)

Any of the following falsifies this DFD formulation:

1. Protocol C yields $\Delta R/R$ consistent with zero at or below $|\Delta\Phi|/c^2$ while dispersion and thermal budgets pass all checks.

2. Protocols A or B yield nulls where DFD predicts nonzero geometry-locked signals after reversals/path swaps.

3. A verified nonzero dispersion ($\partial n/\partial\omega$) fully accounts for any residuals across the band.

Conversely, reproducible nonzero signals that (i) scale with Δh or orientation as predicted, (ii) survive multi-λ tests, and (iii) pass swap/blind controls, would be decisive.

IX. COSMOLOGICAL CONTEXT (BRIEF)

With $\psi \simeq -2\Phi/c^2$, Gordon's metric reproduces classic weak-field optics [1, 8]. DFD suggests that nearby structure can bias line-of-sight cosmography at low z, providing a plausible context for directional H_0 inferences; early-universe constraints (CMB/BAO) remain intact [18, 19].

These motivate but do not underwrite the laboratory program.

X. COMPREHENSIVE RESPONSES TO STANDARD CRITICISMS

(1) "You haven't solved simultaneity; one-way c is conventional." We agree that simultaneity is conventional in SR. DFD makes a different claim: in a *verified nondispersive* band, local phase velocity equals the one-way propagation speed. Our observables are local and synchronization-free; they exploit *route dependence* where GR says strict null. This turns a philosophical impasse into a falsifiable statement [5–7].

(2) "$n = e^{\psi}$ makes $c_1 = c/n$ definitional (circular)." The identity $v_{\text{phase}} = c/n$ follows from standard optics (Fermat/eikonal and Gordon's metric) *independently* [8, 10, 12]. DFD then supplies *dynamics* for ψ (Eq. 1), fixed by classic-test normalization [1]. The bridge is therefore derived, not stipulated.

(3) "Equivalence principle is violated: photons vs matter." Matter test bodies obey $\mathbf{a} = (c^2/2)\nabla\psi$ (universality preserved in weak field). Photons see the optical metric which reproduces GR's lensing/redshift (PPN $\gamma = 1$). Our key test (Protocol C) is an *LPI* probe in the nondispersive vacuum sector; either a residual appears (then LPI is violated in this sector) or it does not (DFD is falsified).

(4) "Lorentz symmetry constraints already exclude this." Two-way isotropy/boost tests [2–4] remain null in DFD. Differences appear only between *paths* sampling different ψ (height/orientation). This is not what SME-style cavity rotations constrain [20].

(5) "Existing optical clocks at different elevations would have seen it." Published redshift verifications are atom–atom or remote-transfer comparisons [13–15]. They confirm GR and are orthogonal to our decisive *co-located cavity–atom <u>ratio</u>* across altitudes. To our knowledge, such a ratio-vs-altitude measurement at $< 10^{-16}$ is not yet published; Protocol C is designed to fill this gap.

(6) "This is just superluminal phase velocity; information rides on front velocity." Correct in dispersive media [16]. Our tests operate in a verified nondispersive band where phase=group=front [10]; the identity is invoked only under those conditions.

(7) "ψ is ad hoc and parameters are tuned." The weak-field normalization is fixed by classic tests; induced-gravity arguments [9] motivate scalar kinetic terms. However, our claims do not hinge on UV priors: the laboratory identity and protocols stand on their own as empirical tests.

XI. CONCLUSIONS

We have turned DFD into a concrete, near-term experimental program: (i) a structural identity that makes phase metrology a one-way-c probe in a verified nondispersive vacuum; (ii) three synchronization-free protocols with GR-null vs DFD-signal contrasts and quantified targets; (iii) an explicit constraints audit and clean refutation logic. The decisive experiment (Protocol C) is implementable now with optical cavities, clocks, and frequency combs. Either the geometry-locked phase-velocity effects appear (opening a new sector of physics) or the present DFD is falsified.

Appendix A: Geometrical optics and nondispersion

Let S be the eikonal: $\mathbf{k} = \nabla S$, $\omega = -\partial_t S$. For $\omega = (c/n)|\mathbf{k}|$, $v_{\text{phase}} = \omega/|\mathbf{k}| = c/n$ and $v_g = \partial\omega/\partial|\mathbf{k}| = c/n$; the Sommerfeld–Brillouin front velocity coincides in the nondispersive limit [10, 16].

Appendix B: Round-trip nulls, clocks, and GPS

For a fixed path γ, $T_{2w} = \frac{2}{c}\int_\gamma n\,\mathrm{d}\ell$; at fixed geometry, orientation rotations preserve two-way times (Michelson–Morley nulls). Clock redshift verifications rely on atom–atom or remote transfers consistent with GR [13–15]; our decisive observable is a *local* cavity–atom ratio across altitude.

Appendix C: Minimal implementation checklist

Cavities: ULE/silicon spacers; PDH locking; cryogenic option; 10^{-17} stability [2, 4].
Fibers: zero-dispersion operation; Faraday isolators; dual-λ phase-tracking [17].
Clocks: Sr/Yb lattice or Al^{+} logic; comb-based ratio readout [13, 14].
Analysis: publish $\sigma_y(\tau)$; blinded reversals; multi-λ linearity fits; environmental logs.

[1] Clifford M. Will. The confrontation between general relativity and experiment. *Living Reviews in Relativity*, 17:4, 2014.

[2] Ch. Eisele, A. Y. Nevsky, and S. Schiller. Laboratory test of the isotropy of light propagation at the 10^{-17} level. *Phys. Rev. Lett.*, 103(9):090401, 2009.

[3] S. Herrmann et al. Rotating optical cavity experiment testing lorentz invariance at the 10^{-17} level. *Phys. Rev. D*, 80(10):105011, 2009.

[4] M. Nagel et al. Direct terrestrial test of lorentz symmetry in electrodynamics to 10^{-18}. *Nature Communications*, 6:8174, 2015.

[5] Hans Reichenbach. *The Philosophy of Space and Time.* Dover, New York, 1958.

[6] W. F. Edwards. Special relativity in anisotropic space. *American Journal of Physics*, 31(7):482–489, 1963.

[7] David Malament. Causal theories of time and the conventionality of simultaneity. *Noûs*, 11(3):293–300, 1977.

[8] Volker Perlick. *Ray Optics, Fermat's Principle, and Applications to General Relativity*, volume 61 of *Lecture Notes in Physics Monographs.* Springer, 2000.

[9] A. D. Sakharov. Vacuum quantum fluctuations in curved space and the theory of gravitation. *Sov. Phys. Dokl.*, 12:1040–1041, 1968.

[10] Max Born and Emil Wolf. *Principles of Optics.* Cambridge University Press, 7 edition, 1999.

[11] John D. Jackson. *Classical Electrodynamics.* Wiley, New York, 3 edition, 1998.

[12] W. Gordon. Zur lichtfortpflanzung nach der relativitätstheorie. *Annalen der Physik*, 377(22):421–456, 1923.

[13] C. W. Chou, D. B. Hume, T. Rosenband, and D. J. Wineland. Optical clocks and relativity. *Science*, 329(5999):1630–1633, 2010.

[14] W. F. McGrew et al. Atomic clock performance enabling geodesy below the centimetre level. *Nature*, 564:87–90, 2018.

[15] P. Delva et al. Gravitational redshift test using eccentric galileo satellites. *Phys. Rev. Lett.*, 121(231101), 2018.

[16] Léon Brillouin. *Wave Propagation and Group Velocity.* Academic Press, 1960.

[17] Govind P. Agrawal. *Fiber-Optic Communication Systems.* Wiley, 4 edition, 2010.

[18] Planck Collaboration. Planck 2018 results. vi. cosmological parameters. *Astronomy & Astrophysics*, 641:A6, 2020.

[19] A. G. Riess et al. A comprehensive measurement of the local value of the hubble constant with 1 km s^{-1} mpc^{-1} uncertainty from the hubble space telescope and the sh0es team. *Astrophys. J. Lett.*, 934(1):L7, 2022.

[20] V. Alan Kostelecký and Neil Russell. Data tables for lorentz and cpt violation. *Rev. Mod. Phys.*, 83:11, 2011. January 2024 update available at arXiv:0801.0287.