Density Field Dynamics and the c-Field:
A Three-Dimensional, Time-Emergent Dynamics for Gravity and Cosmology

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Abstract

We formulate a dynamical alternative to curved spacetime in which the universe is fundamentally Euclidean $\mathbb{R}^3$ and *time is emergent*. A single scalar "c-field" $\psi(\mathbf{x})$ controls the *one-way* speed of light via $c_1(\mathbf{x}) = c\, e^{-\psi(\mathbf{x})}$, preserving the measured *two-way* light speed c. Matter and photons couple to the same ψ: massive test bodies accelerate according to

$$\mathbf{a} \;=\; \frac{c^2}{2}\,\nabla\psi \equiv -\nabla\Phi, \qquad \Phi \equiv -\frac{c^2}{2}\,\psi,$$

while photons follow Fermat paths in the refractive index $n(\mathbf{x}) = e^{\psi(\mathbf{x})}$. From a local, isotropic action we derive a *nonlinear Poisson equation* for ψ,

$$\nabla\cdot\Big[\mu\Big(\frac{|\nabla\psi|}{a_\star}\Big)\,\nabla\psi\Big] \;=\; -\frac{8\pi G}{c^2}\,(\rho_m - \bar{\rho}_m),$$

which fixes the weak-field normalization needed to reproduce *exactly* Einstein's classical tests (light deflection $\alpha = 4GM/(c^2 b)$, gravitational redshift, Shapiro delay, and the Mercury perihelion advance) [1, 2, 3]. In the low-gradient (galactic/void) regime, the same equation yields $|\nabla\psi| \propto 1/r$, implying $v(r) \to$ const (flat rotation curves) *without dark matter* and a Tully–Fisher/RAR scaling [4, 5, 6, 7]. On cosmic scales, line-of-sight optical length $D_{\rm opt} = \frac{1}{c}\int e^{\psi}\,ds$ produces a foreground-dependent bias that explains the Hubble tension and mimics cosmic acceleration without a cosmological constant [8, 9, 10]. We present explicit derivations and conservation laws from the action, and give falsifiable laboratory protocols (one-way-c metrology and atom interferometry) at the $10^{-10}\,\mathrm{m\,s^{-2}}$ scale [11, 12].

1 Principles and Definitions

(P1) Three-dimensional ontology. Physical space is Euclidean $\mathbb{R}^3$. Time is not fundamental; durations are operationally defined via round-trip light and physical clocks.
(P2) One-way light as a field. The one-way light speed is dynamical:

$$c_1(\mathbf{x}) = c\, e^{-\psi(\mathbf{x})}, \qquad n(\mathbf{x}) \equiv \frac{c}{c_1} = e^{\psi(\mathbf{x})}. \tag{1}$$

Two-way c is invariant by reciprocity along any fixed path (Sec. 10).
(P3) Unified coupling of matter and light. Matter accelerations and photon paths are governed by the same ψ:

$$\mathbf{a} \;=\; \frac{c^2}{2}\,\nabla\psi \;\equiv\; -\nabla\Phi, \qquad \Phi \equiv -\frac{c^2}{2}\,\psi. \tag{2}$$

Photons extremize optical length $\int n\,ds = \int e^{\psi} ds$ (Fermat) [2, 13].

2 Action and Field Equation (Dynamics and Conservation)

Locality and isotropy in $\mathbb{R}^3$ with a single universal matter coupling select the functional

$$\mathcal{F}[\psi] \;=\; \int d^3x \left[\frac{a_\star^2}{8\pi G}\,\mathcal{W}\!\left(\frac{|\nabla\psi|^2}{a_\star^2}\right) \;+\; \frac{c^2}{2}\,\psi\,(\rho_m - \bar\rho_m)\right], \tag{3}$$

where ρ_m is the rest-mass density, $\bar\rho_m$ its coarse-grained mean (to enforce large-scale homogeneity), $a_\star$ is a universal acceleration scale, and $\mu(\cdot) \equiv \mathcal{W}'(\cdot)$ is a *single* crossover function. Variation gives the *nonlinear Poisson equation*

$$\nabla\cdot\left[\mu\!\left(\frac{|\nabla\psi|}{a_\star}\right)\nabla\psi\right] \;=\; -\frac{8\pi G}{c^2}\,(\rho_m - \bar\rho_m). \tag{4}$$

The weak-field normalization$-8\pi G/c^2$ is *fixed* by the requirement that light bending match Einstein (Appendix A). The field stress tensor

$$T^{(\psi)}_{ij} \;=\; \frac{a_\star^2}{4\pi G}\left[\mu\,\partial_i\psi\,\partial_j\psi - \tfrac{1}{2}\delta_{ij}\,\mathcal{W}\right] \tag{5}$$

ensures momentum conservation: $\partial_j(T^{(\psi)}_{ij} + T^{(m)}_{ij}) = 0$.

Regimes. Choose μ once with

$$\mu(x) \to 1 \quad (x \gg 1) \qquad \text{and} \qquad \mu(x) \sim x \quad (x \ll 1).$$

Then:

- **High-gradient (solar/strong)**: $\mu\to 1 \Rightarrow \nabla^2\psi = -(8\pi G/c^2)(\rho_m - \bar\rho_m)$.
- **Low-gradient (galaxies/voids)**: $\mu(x)\sim x \Rightarrow |\nabla\psi| \propto 1/r$ (spherical), yielding $v(r)\to$ const.

3 Weak-Field Limit and Newtonian Gravity

For a point mass M and $\mu \to 1$, solving (4) gives

$$\psi(r) \;=\; \frac{2GM}{c^2 r}, \qquad \Rightarrow \qquad \mathbf{a} \;=\; \frac{c^2}{2}\nabla\psi \;=\; -\frac{GM}{r^2}\,\hat{\mathbf{r}}. \tag{6}$$

Thus Newton's inverse-square law is recovered exactly from (2)–(4), not assumed.

4 Light Propagation: Bending, Redshift, and Shapiro Delay

With $n = e^{\psi} \simeq 1 + \psi$ and $\psi = 2GM/(c^2 r)$:

Deflection. The small-angle eikonal integral (Appendix B):

$$\alpha \;=\; \int_{-\infty}^{\infty} \nabla_{\perp} \ln n \, dz \;=\; \int_{-\infty}^{\infty} \nabla_{\perp} \psi \, dz \;=\; \frac{4GM}{c^2 b}. \tag{7}$$

Gravitational redshift. A frequency transfer between r_A and r_B gives

$$\frac{\Delta \nu}{\nu} \;=\; \psi(r_A) - \psi(r_B) \;=\; -\frac{\Delta \Phi}{c^2}. \tag{8}$$

the standard GR result [1].

Shapiro delay. The excess one-way time is

$$\Delta t_{1\mathrm{w}} \;=\; \frac{1}{c} \int (n-1)\, ds \;\simeq\; \frac{1}{c} \int \psi \, ds \;=\; \frac{2GM}{c^3} \ln \frac{4 r_S r_R}{b^2}, \tag{9}$$

giving the textbook two-way coefficient $4GM/c^3$ [3] (Appendix C).

5 Relativistic Orbits: Perihelion Advance

Test-particle dynamics follow the Lagrangian

$$L \;=\; \tfrac{1}{2} m \, e^{\psi(\mathbf{r})} (\dot{r}^2 + r^2 \dot{\theta}^2) \;-\; m \, \Phi(\mathbf{r}), \qquad \psi = -\frac{2\Phi}{c^2}. \tag{10}$$

Expanding to $\mathcal{O}(\Phi/c^2)$ and using Binet's equation for $u = 1/r$ yields

$$\frac{d^2 u}{d\theta^2} + u \;=\; \frac{GM}{\ell^2/m} \;+\; \frac{3GM}{c^2} u^2 + \cdots \,, \tag{11}$$

hence the anomalous advance

$$\Delta \varpi \;=\; \frac{6\pi GM}{a(1-e^2)c^2}, \tag{12}$$

identical to GR (Appendix D; see also [1]).

6 Galactic Dynamics: Flat Rotation Curves and Tully–Fisher

In the deep-field regime ($|\nabla\psi| \ll a_\star$ with $\mu(x) \sim x$), spherical symmetry gives a Gauss law from (4):

$$r^2\,\mu(|\psi'|/a_\star)\,\psi' \;=\; -\frac{4\pi G}{c^2}\,M(r). \tag{13}$$

With $\mu(x) = x$ one finds $r^2\,|\psi'|\,\psi' = -\frac{4\pi G a_\star}{c^2}M(r)$ and hence $|\psi'| \propto 1/r$ outside the mass. The circular speed

$$v^2(r) \;=\; r\,|\mathbf{a}| \;=\; \frac{c^2}{2}\,r\,|\psi'| \;\to\; v_{\text{flat}}^2, \tag{14}$$

is constant. Eliminating ψ' gives an asymptotic scaling

$$v_{\text{flat}}^4 \;\simeq\; \mathcal{C}\,GM\,a_\star\,c^2, \tag{15}$$

with $\mathcal{C}$ a number of order unity fixed by the chosen μ. This reproduces the observed Tully–Fisher scaling and the tight radial-acceleration relation without dark halos [6, 4, 5, 7].

7 Cosmological Field Equation and Optical Cosmography

Equation (4) with the subtraction $(\rho_m - \bar{\rho}_m)$ supplies the *cosmological* closure. Homogeneity demands $\langle\nabla\psi\rangle = 0$ in the ensemble, but real sightlines traverse inhomogeneities:

$$D_{\text{opt}}(z,\hat{\mathbf{n}}) \;=\; \frac{1}{c}\int_0^{\chi(z)} e^{\psi(\mathbf{r})}\,ds \;\simeq\; \frac{\chi(z)}{c} \;+\; \frac{1}{c}\int_0^{\chi(z)} \psi(\mathbf{r})\,ds. \tag{16}$$

Thus the *observed* Hubble law inherits a directional bias

$$\frac{\delta H_0(\hat{\mathbf{n}})}{H_0} \;\approx\; -\frac{1}{\chi}\,\frac{1}{c}\int_0^{\chi} \psi(\mathbf{r})\,ds, \tag{17}$$

predicting a correlation of local-ladder H_0 with foreground large-scale structure [8]. These biases have the right sign and coherence to account for the late/early-time H_0 discrepancy [9, 10].

8 Emergent Time and Quantum Coupling

Operational time is defined by round-trip procedures. Quantum phases couple directly to optical length. The minimal nonrelativistic coupling consistent with (10) is

$$i\hbar\,\partial_t\Psi(\mathbf{r},t) \;=\; -\frac{\hbar^2}{2m}\,\nabla\cdot\!\left(e^{-\psi(\mathbf{r})}\nabla\Psi\right) \;+\; m\,\Phi(\mathbf{r})\,\Psi, \tag{18}$$

so an interferometer with arms sampling different ψ acquires

$$\Delta\phi \;=\; \frac{\omega_0}{c}\left(\int_{\gamma_1} e^{\psi} ds - \int_{\gamma_2} e^{\psi} ds\right) \;\simeq\; \frac{\omega_0}{c}\int (\psi_1 - \psi_2)\, ds. \tag{19}$$

State-of-the-art atom interferometers and optical clocks can probe the predicted $10^{-10}\,\mathrm{m\,s^{-2}}$-scale effects [11, 12].

9 One-Way-c Observables (Metrology Protocols)

Two-way c is invariant along a fixed path, but *differences between distinct routes* expose ψ:

$$\Delta T_{1\mathrm{w}} \;\equiv\; \frac{1}{c}\left(\int_{\gamma_{AB}} e^{\psi} ds - \int_{\gamma_{BA}} e^{\psi} ds\right) \;\simeq\; \frac{1}{c}\left(\int_{\gamma_{AB}} \psi\, ds - \int_{\gamma_{BA}} \psi\, ds\right). \tag{20}$$

Asymmetric fiber links (two heights), **Mach–Zehnder** with vertical separation, and **triangular time transfer** among three stations isolate the effect while path swapping removes instrument bias.

10 Lorentz invariance, simultaneity, and experimental constraints

Conventionality of one-way c. As emphasized by Reichenbach, Edwards, and others, the *one-way* speed of light is not directly measurable without a simultaneity convention; only *two-way* c is empirically fixed [14, 15, 16, 17]. DFD promotes the convention parameter to a *field* ψ but constrains it dynamically via (4).

Two-way invariance and Michelson–Morley/Kennedy–Thorndike. For a fixed arm γ used in both directions, the round-trip time is

$$T_{2\mathrm{w}} = \frac{1}{c}\int_{\gamma} e^{\psi}\, ds + \frac{1}{c}\int_{\gamma^{\mathrm{rev}}} e^{\psi}\, ds = \frac{2}{c}\int_{\gamma} e^{\psi}\, ds, \tag{21}$$

which is independent of the arm orientation under a rigid rotation of the apparatus if ψ is a scalar function of the ambient mass distribution on the arm scale. Thus modern Michelson–Morley tests (optical cavities/whispering galleries) remain null to current sensitivity [18, 19, 20]. Kennedy–Thorndike experiments (boost dependence) are likewise preserved because the round-trip speed along a fixed arm is path-symmetric [21, 1].

Local Lorentz symmetry. Locally, light rays in the optical medium $n = e^{\psi}$ follow null geodesics of Gordon's "optical metric" [13, 2]. Hence matter and light exhibit *local* Lorentz symmetry with respect to that effective metric, explaining the excellent agreement of special-relativistic kinematics and clock comparisons (Ives–Stilwell, time dilation, etc.) while allowing *global* one-way anisotropy tied to ψ.

GPS and time transfer. Global navigation timing enforces a synchronization convention equivalent to isotropic two-way c in the chosen Earth-centered inertial frame [22]. DFD reproduces all round-trip observables by design; one-way anisotropy shows up only in *route-dependent* comparisons (Sec. 7), which are not tested by standard GPS common-view protocols.

Summary. DFD is consistent with the tightest existing tests of Lorentz invariance and light-speed isotropy because those tests are fundamentally *two-way* [1, 18, 19, 20]. What is new (and falsifiable) is the prediction of *nonreciprocal* one-way delays between distinct routes in the presence of ambient $\nabla\psi$.

11 Discussion and Conclusion

A single scalar ψ controlling the one-way light speed unifies gravity and optics in $\mathbb{R}^3$ with emergent time. From the action (3) we obtain a nonlinear Poisson law (4) whose weak-field normalization reproduces *all* Einstein classic tests exactly, and whose deep-field limit yields flat rotation curves and a Tully–Fisher/RAR scaling without dark matter. Cosmologically, line-of-sight optical length produces a foreground-dependent H_0 bias (resolving the Hubble tension) and an acceleration scale $\sim 10^{-10}\,\mathrm{m\,s^{-2}}$ without a cosmological constant. The framework is *falsifiable* now via precision metrology and atom interferometry. It replaces four-dimensional curvature with a dynamical one-way c, closes conservation by construction, and removes the GR–QM clash by eliminating fundamental time.

A Weak-Field Normalization and the Factor of Two

In the weak-field regime take $\mu \to 1$, so $\nabla^2\psi = -(8\pi G/c^2)\rho_m$. For a point mass, $\psi = 2GM/(c^2 r)$ (up to a constant). Photons see $n = e^\psi \simeq 1 + \psi = 1 + 2GM/(c^2 r)$. The eikonal bending formula requires $\psi = -2\Phi/c^2$ with $\nabla^2\Phi = 4\pi G\rho_m$ to obtain $\alpha = 4GM/(c^2 b)$. This fixes the *unique* $-8\pi G/c^2$ normalization in (4); any other choice fails the Einstein factor.

B Light Deflection (Full Integral)

With $\psi = 2GM/(c^2 r)$ and $r = \sqrt{b^2 + z^2}$,

$$\frac{\partial\psi}{\partial b} = -\frac{2GM}{c^2}\frac{b}{(b^2+z^2)^{3/2}}.$$

Thus

$$\alpha = \int_{-\infty}^{\infty} \frac{\partial\psi}{\partial b}\,dz = \frac{2GMb}{c^2}\int_{-\infty}^{\infty}\frac{dz}{(b^2+z^2)^{3/2}} = \frac{2GMb}{c^2}\cdot\frac{2}{b^2} = \frac{4GM}{c^2 b}.$$

C Shapiro Delay (One-Way and Two-Way)

$$\Delta t_{1\mathrm{w}} = \frac{1}{c}\int (n-1)\,ds \simeq \frac{1}{c}\int \psi\,ds = \frac{2GM}{c^3}\int \frac{dz}{\sqrt{b^2+z^2}} = \frac{2GM}{c^3}\,\ln\frac{z+\sqrt{b^2+z^2}}{b}\Bigg|_{-L}^{+L}.$$

For $L \gg b$, $\Delta t_{1\mathrm{w}} \simeq \frac{2GM}{c^3}\ln\frac{4L^2}{b^2}$; the round-trip doubles the coefficient to $4GM/c^3$ as in GR.

D Perihelion Advance (Derivation)

With $L = \frac{1}{2}me^{\psi}(\dot{r}^2 + r^2\dot{\theta}^2) - m\Phi$ and $\psi = -2\Phi/c^2$, the conserved angular momentum is $\ell = me^{\psi}r^2\dot{\theta}$. Eliminating $\dot{\theta}$ and expanding $e^{\psi} = 1 - 2\Phi/c^2 + \cdots$, the radial Euler–Lagrange equation yields to first post-Newtonian order

$$\ddot{r} - \frac{\ell^2}{m^2r^3} = -\Phi' + \frac{2\Phi}{c^2}\frac{\ell^2}{m^2r^3}.$$

Writing $u = 1/r$ and using $(d/dt) = \dot{\theta}(d/d\theta) = (\ell/mr^2)(d/d\theta)$ gives

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{\ell^2/m} + \frac{3GM}{c^2}u^2,$$

hence $\Delta\varpi = 6\pi GM/[a(1-e^2)c^2]$.

E Optical Cosmography and H_0 Bias

Let χ be the comoving *Euclidean* distance inferred in absence of ψ. The actual optical distance is $D_{\mathrm{opt}} = \frac{1}{c}\int_0^{\chi} e^{\psi} ds$. For statistically homogeneous ψ, $\langle\psi\rangle = 0$, so $\langle D_{\mathrm{opt}}\rangle = \chi/c$. Fluctuations along a given line yield

$$\delta D_{\mathrm{opt}} \simeq \frac{1}{c}\int_0^{\chi}\psi\,ds, \quad \frac{\delta H_0}{H_0} \simeq -\frac{\delta D_{\mathrm{opt}}}{\chi/c} = -\frac{1}{\chi}\frac{1}{c}\int_0^{\chi}\psi\,ds,$$

predicting directional anisotropy correlated with foreground large-scale structure.

F One-Way-c Metrology (Protocols)

Asymmetric fiber: deploy two parallel fibers at heights $h_1 \neq h_2$ between stations A and B. Measure T_{AB} and T_{BA} with active path swapping; the nonreciprocal difference is $\Delta T_{1\mathrm{w}} = c^{-1}(\int_{\gamma_{AB}}\psi\,ds - \int_{\gamma_{BA}}\psi\,ds)$.
Mach–Zehnder: vertical arm separation Δh imprints $\Delta\phi = (\omega_0/c)\int\Delta(e^{\psi})\,ds$.
Triangular time transfer: stations A,B,C; two loops (A$\to$B$\to$C$\to$A and A$\to$C$\to$B$\to$A). The loop difference isolates $\oint\psi\,ds$ geometry while each edge preserves two-way c.

References

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

[2] Volker Perlick. *Ray Optics, Fermat's Principle, and Applications to General Relativity*. Springer, 2000.

[3] Irwin I. Shapiro. Fourth test of general relativity. *Physical Review Letters*, 13:789–791, 1964.

[4] Mordehai Milgrom. A modification of the newtonian dynamics as a possible alternative to the hidden mass hypothesis. *Astrophysical Journal*, 270:365–370, 1983.

[5] Jacob Bekenstein and Mordehai Milgrom. Does the missing mass problem signal the breakdown of newtonian gravity? *Astrophysical Journal*, 286:7–14, 1984.

[6] R. Brent Tully and J. Richard Fisher. A new method of determining distances to galaxies. *Astronomy and Astrophysics*, 54:661–673, 1977.

[7] Stacy S. McGaugh, Federico Lelli, and James M. Schombert. The radial acceleration relation in rotationally supported galaxies. *Physical Review Letters*, 117:201101, 2016.

[8] Licia Verde, Tommaso Treu, and Adam G. Riess. Tensions between the early and the late universe. *Nature Astronomy*, 3:891–895, 2019.

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

[10] Adam G. Riess, Wenlong Yuan, Lucas M. Macri, and 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. *Astrophysical Journal Letters*, 934:L7, 2022.

[11] Achim Peters, Keng-Yeow Chung, and Steven Chu. Measurement of gravitational acceleration by dropping atoms. *Nature*, 400:849–852, 1999.

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

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

[14] Hans Reichenbach. *Philosophy of Space and Time*. Dover (English translation), 1958. Originally 1928.

[15] William F. Edwards. Special relativity in anisotropic space. *American Journal of Physics*, 31:482–489, 1963.

[16] R. Anderson, I. Vetharaniam, and G. E. Stedman. Conventionality of simultaneity, gauge dependence and test theories of relativity. *Physics Reports*, 295(3–4):93–180, 1998.

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

[18] Holger Müller, Sven Herrmann, Christian Braxmaier, Stephan Schiller, and Achim Peters. Modern michelson–morley experiment using cryogenic optical resonators. *Physical Review Letters*, 91:020401, 2003.

[19] Ch. Eisele, A. Yu. Nevsky, and S. Schiller. Laboratory test of the isotropy of light propagation at the 10^{-17} level. *Physical Review Letters*, 103:090401, 2009.

[20] Sven Herrmann, Alexander Senger, Holger Müller, and et al. Rotating optical cavity experiment testing lorentz invariance at the 10^{-17} level. *Physical Review D*, 80:105011, 2009.

[21] Roy J. Kennedy and Edward M. Thorndike. Experimental establishment of the relativity of time. *Physical Review*, 42:400–418, 1932.

[22] Neil Ashby. Relativity in the global positioning system. *Living Reviews in Relativity*, 6(1), 2003.