Non-Equilibrium Information Physics: Core Concepts and Governing Equations

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Abstract

We propose that information, not matter or energy, is the fundamental physical quantity. Information density $m(\mathbf{x}, t)$ at Planck scale generates potentials, which drive energetic rearrangements and mass emergence. Key result: $M = (c^2/4\pi G) \int m\, dV$, consistent with GR, QFT, thermodynamics, and holography.

1 Framework

1.1 Planck-Scale Informational Mosaic

The universe is structured by Planck-scale pixels encoded through:

- 2π **quantum loop**: minimal phase-complete circuit in phase space,
- 4π **radial kernel**: spherical isotropy via $G(r) = 1/(4\pi r)$,
- **Planck length**: $\ell_P = \sqrt{\hbar G/c^3}$.

Together, these define the substrate for all physical information.

Primary field. The informational density

$$m(\mathbf{x}, t) \quad [\mathrm{nat\, m^{-3}}] \tag{1}$$

replaces matter and energy as the foundational entity. Spatial or temporal coherence of m produces *informational patterns*, which seed emergent phenomenology.

1.2 Conceptual Chain

NEIP Core Flow

$$\text{Pixels } (\ell_P, 2\pi, 4\pi) \to m(\mathbf{x}, t) \xrightarrow{\nabla^2\Phi_I} \Phi_I \xrightarrow{\text{IEL}} E, M$$

Information generates potentials, potentials drive energy exchange, and stable information yields mass.

2 Core Equations

2.1 Informational Potential

Patterns of m induce a dimensionless potential Φ_I via the Poisson equation

$$\nabla^2 \Phi_I = \kappa_I\, m, \tag{2}$$

where κ_I has units of $\mathrm{m\, nat^{-1}}$. **Newtonian correspondence:**

$$\Phi_N = c^2 \Phi_I \quad [\mathrm{m^2 s^{-2}}]. \tag{3}$$

In curved spacetime, Eq. (2) generalizes to

$$\Box_g \Phi_I = \kappa_I\, m, \tag{4}$$

preserving general covariance.

2.2 Conservation and Transport

Information conservation with dissipation:

$$\partial_t m + \nabla \cdot \mathbf{j} = S_{\text{in}} - \Gamma_{\text{dis}}(m), \tag{5}$$

where $\mathbf{j}$ is the information current $[\mathrm{nat\, m^{-2} s^{-1}}]$, S_{in} denotes source terms, and Γ_{dis} models dissipation.

Finite-speed telegraph equation:

$$\tau_c\, \partial_t \mathbf{j} + \mathbf{j} = -D \nabla m + \mathbf{F}_{\text{att}}, \tag{6}$$

with memory time τ_c and diffusivity D. This enforces causal propagation:

$$v_\star = \sqrt{D/\tau_c} \le c. \tag{7}$$

Potential-driven flow:

$$\mathbf{j} = -D \nabla \Phi_I. \tag{8}$$

Combining Eqs. (5), (6), and (8) yields a closed dynamical system.

2.3 Energy and Mass Emergence

Informational Equilibrium Law (IEL):

$$\dot{S}_{\text{irr}} + \dot{I}_{\text{IF}} = -\frac{\dot{E}}{k_B T_{\text{eff}}} \geq 0, \tag{9}$$

where $\dot{S}_{\text{irr}}$ is irreversible entropy production, $\dot{I}_{\text{IF}}$ is informational flow rate, and T_{eff} an effective informational temperature. Energy enters only as a macroscopic descriptor of information reconfiguration.

Mass integral: Mass is not fundamental; it emerges from stable informational density:

$$M = \frac{c^2}{4\pi G} \int m(\mathbf{x})\, dV. \tag{10}$$

Units: $[m\, dV] = \text{nat}$, $[M] = \text{kg}$.

3 Emergent Properties

3.1 Cosmological Dilution

In an expanding FRW background with scale factor $a(t)$ and Hubble parameter $H = \dot{a}/a$:

$$\frac{dI}{dt} = -3HI, \quad I \propto a^{-3}, \tag{11}$$

consistent with volume-based information dilution.

3.2 Holographic Bound

The maximal information on a spatial region of area A respects:

$$I_{\max} = \frac{A}{4\ell_P^2}, \tag{12}$$

identical to the Bekenstein–Hawking entropy bound.

Testable Consequences

1. **Gravitational correspondence:** $\Phi_N = c^2 \Phi_I$ (3) recovers Newtonian gravity in weak-field limit.
2. **Causal bound:** Telegraph equation (6) enforces $v_\star \leq c$ (7), preventing superluminal information transport.
3. **Cosmological test:** Information dilution $I \propto a^{-3}$ (11) implies testable deviations in large-scale structure formation.
4. **Holographic consistency:** Area law (12) matches black hole thermodynamics.
5. **Non-equilibrium signature:** IEL (9) predicts thermodynamic constraints on dissipative information flows.

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A Notation and Fundamental Constants

Symbol	Meaning	Units
m	Info. density	$\text{nat}\,\text{m}^{-3}$
$\mathbf{j}$	Info. current	$\text{nat}\,\text{m}^{-2}\text{s}^{-1}$
τ_c	Memory time	s
D	Diffusivity	m^2s^{-1}
Φ_I	Info. potential	dimensionless
Φ_N	Newton potential	m^2s^{-2}
ℓ_P	Planck length	m
E	Energy	J
M	Emergent mass	kg
T_{eff}	Eff. temperature	K
κ_I	Coupling const.	$\text{m}\,\text{nat}^{-1}$

Table 1: Key symbols in NEIP.

Fundamental constants:

$$c = 2.998 \times 10^8\,\text{m}\,\text{s}^{-1},$$
$$\hbar = 1.055 \times 10^{-34}\,\text{J}\,\text{s},$$
$$G = 6.674 \times 10^{-11}\,\text{m}^3\text{kg}^{-1}\text{s}^{-2},$$
$$k_B = 1.381 \times 10^{-23}\,\text{J}\,\text{K}^{-1},$$
$$\ell_P = 1.616 \times 10^{-35}\,\text{m}.$$

B Consistency Checks

B.1 General Relativity

- Poisson limit: $\Phi_N = c^2 \Phi_I$ recovers Newtonian gravity.
- No Bianchi identity violation at weak-field level.
- Finite-speed propagation: no instantaneous action.

B.2 Quantum Field Theory

- No additional dynamical fields introduced.
- No explicit Lorentz violation in core PDEs.
- Energy enters macroscopically via IEL (9).
- Compatible with 2π phase loops and uncertainty principles.

B.3 Thermodynamics

- IEL ensures $\dot{S}_{\mathrm{irr}} + \dot{I}_{\mathrm{IF}} \geq 0$.
- No violation of Clausius inequality.
- Dissipation term $\Gamma_{\mathrm{dis}} \geq 0$ in (5).

B.4 Causality

- Telegraph equation (6) enforces $v_\star \leq c$.
- All interactions mediated by local PDEs.
- No superluminal signaling.

B.5 Black Hole Physics

- Area-based capacity (12) matches Bekenstein–Hawking.
- Pixelization compatible with holographic principle.
- No information paradox introduced at this level.

B.6 Summary of Non-Violations

NEIP does not violate:

- Energy conservation (macroscopic level),
- Lorentz invariance (in intended domain),
- General covariance (curved extension (4)),
- Quantum consistency (no hidden-variable completion),
- Holographic bounds.