Foundations of FTDIE

From the conservation principle to field equations — Volume 1

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Functional Theory of Information and Energy Dynamics

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Introduction

This volume presents the foundations of the Functional Theory of Information and Energy Dynamics (FTDIE) — from the single axiom $\Omega = \text{const}$ (information-energy conservation principle) to full field equations, conformal transformation, and observational constraints.

The volume begins with an introduction to FTDIE: the genesis of the theory, the operational definition of Fisher information, construction of the Lagrangian, full variational derivation of the field equations, conformal transformation to the Einstein frame, and comparison with Brans–Dicke and Horndeski theories. This is followed by the ontological reinterpretation (particles as topology of space), cosmological genesis as a phase transition, restoration of the energy conservation law, and emergence of the dark sector from the field Φ.

Every chapter contains complete mathematical derivations — nothing is truncated.

Chapter 1

Introduction

1.1 Genesis of the theory — from intuition to formalism

The FTDIE theory grew out of a single intuitive assumption of the author:

> *The Universe is invariant with respect to the total amount of energy and information. Information does not arise for free — its creation requires the expenditure of energy.*

The formalisation of this idea proceeded in four steps.

Step 1: Energy–information balance

The starting point is the equation:

$$\Omega \;=\; E \;+\; k\,\mathcal{I}\,, \tag{1.1}$$

where E is the energy, $\mathcal{I}$ is the amount of information, and k is the energetic cost of creating one bit of information. The assumption that this balance is invariant, both **locally** and **globally**, leads to the condition:

$$\boxed{\delta\Omega = 0\,.} \tag{1.2}$$

Step 2: Landauer's principle as a bridge to physics

The inspiration for identifying the above balance with measurable physics was **Landauer's principle** [?]: erasing one bit of information releases a measurable energy $E_L = k_B T \ln 2$. If erasing a bit produces energy, then — by symmetry — **creating a bit must consume** an equivalent amount of energy. Hence the constant k in equation (1.1) acquires a physical meaning: it is the thermodynamic cost of information creation.

Step 3: Original forms of the coupling function and potential

The following original forms were introduced:

$$f(\varphi) = f_0\big(1 + \xi\,\varphi\big)\,, \tag{1.3}$$

$$V(\varphi) = A\,\varphi\;\tanh\!\left(\frac{\beta\,\varphi}{1 + \gamma\,\varphi^2}\right), \tag{1.4}$$

where f_0 corresponds to the effective stiffness of the information vacuum, ξ is the coupling parameter of the field to curvature, A sets the energy scale, β controls the saturation of the potential, and γ stabilises it for large field values.

The linear coupling (1.3) expresses the simplest realisation of the idea that the information field φ modifies the effective gravitational constant. The potential (1.4) with the tanh function ensures saturation — for large φ the potential does not grow without bound, which corresponds to the physical intuition of a finite information capacity.

Step 4: From a global balance to a field density

The transition from the global quantity Ω to a field theory requires replacing the information content $\mathcal{I}$ by a **field density** $\Phi(x)$ defined at every point of spacetime. The balance (1.1) becomes a Lagrangian density:

$$\mathcal{L} = f(\Phi)\, R + \tfrac{1}{2}\, g^{\mu\nu}\partial_\mu\Phi\, \partial_\nu\Phi - V(\Phi)\,, \tag{1.5}$$

and the condition $\delta\Omega = 0$ becomes the principle of least action:

$$\delta S = \delta \int d^4x\, \sqrt{-g}\, \mathcal{L} = 0\,. \tag{1.6}$$

In the subsequent analysis — in particular in the inflationary and cosmological calculations (Parts II–IX) — we adopt the standard quadratic form:

$$f(\Phi) = \tfrac{1}{2}\bar{M}_{\rm Pl}^2 + \xi\, \Phi^2\,, \tag{1.7}$$

which is a special case of the Brans–Dicke class, well studied in the literature and yielding unambiguous observational predictions (n_s, r). The original forms (1.3)–(1.4) remain a fully valid starting point — their detailed phenomenology is the subject of further research.

1.2 What is FTDIE

The Functional Theory of Information and Energy Dynamics (FTDIE) is a framework physics program that interprets a specific scalar–tensor theory of gravity through the lens of information dynamics. The starting point is the action:

$$S[\Phi, g_{\mu\nu}] = \int d^4x\, \sqrt{-g}\, \left[f(\Phi)\, R + \tfrac{1}{2}\, g^{\mu\nu}\partial_\mu\Phi\, \partial_\nu\Phi - V(\Phi)\right], \tag{1.8}$$

with the coupling function $f(\Phi) = \frac{1}{2}\bar{M}_{\rm Pl}^2 + \xi\Phi^2$ and the potential $V(\Phi) = \frac{1}{2}m_\Phi^2\Phi^2 + \frac{\lambda}{4!}\Phi^4$, where $\bar{M}_{\rm Pl} = M_{\rm Pl}/\sqrt{8\pi}$ is the reduced Planck mass. The metric signature is $(-,+,+,+)$.

Mathematically, the Lagrangian (1.8) is a special case of Horndeski's theory [**?**] and a generalisation of Brans–Dicke theory [**?**]. We state this explicitly at the outset, because honesty towards the existing body of work is a fundamental scientific principle. What FTDIE contributes beyond the known scalar–tensor formalism is:

[label=()]**Information interpretation**: the field Φ is treated as an information density field, and its coupling to curvature expresses the physical principle that information has weight (an analogy with Landauer's principle [**?**]). **Specific choice** of $f(\Phi)$, motivated by Fisher information (see §3). **Emergence programme**: the postulate that from the dynamics of a single scalar field coupled to geometry one can derive gravity, gauge fields, fermions, and cosmology as different regimes of the same system.

1.3 A note on language and the status of claims

Throughout this monograph we employ a strict distinction between:

- **"we prove"** — used exclusively for rigorous mathematical derivations (e.g. variation of the action, Bianchi identity);
- **"we argue"** / **"we show"** — for physical reasoning that relies on physical assumptions, approximations, or identifications (e.g. Φ as the information field);
- **"we propose"** / **"we postulate"** — for hypotheses that do not follow from the formalism but constitute the starting point of the programme;
- **"we predict"** — for testable consequences that reversibly falsify the theory.

1.4 Overview of the monograph

The monograph consists of seven parts:

1. **Part I — Foundations of FTDIE** (the present one): operational definition of information, relation to existing theories, full derivation of the field equations, conformal transformation, observational constraints.
2. **Part II — Cosmology**: inflation (analogy with the Bezrukov–Shaposhnikov model [?]), perturbations, dark matter as oscillations of Φ, dark energy.
3. **Part III — Emergence of interactions**: Maxwell's equations, gauge symmetries, the full Standard Model.
4. **Part IV — Emergent graviton**: quantisation, spin-2 sector, propagator, coupling, nonlinearity.
5. **Part V — UV completeness**: emergent graviton dissolution, asymptotic safety.
6. **Part VI — The problem of time and entropy**: deparametrisation of Wheeler–DeWitt, Bekenstein–Hawking entropy.
7. **Part VII — Predictions and perspectives**: testable signatures, open problems, research programme.

Chapter 2

Genesis of FTDIE structures — from one cause to all of physics

Physics does not create axioms. Nature creates itself from the simplest possible causes. In this section we show that the *entire* structure of FTDIE — gauge fields, Standard-Model symmetries, gravitation, fermions — grows from a single statement and the principle of necessity. What were previously called "axioms" become links in a single chain.

2.1 One cause

> **(P) Information exists and cannot be zero.**

This is not a postulate — it is an observation. Whatever exists carries information. Absolute vacuum (zero information) would mean that nothing exists, not even the statement that nothing exists. This is a logical contradiction, not a physical assumption.

Physical proof of (P). The statement $|\Phi|^2 = 0$ in any spacetime region requires a measurement over a finite time Δt. By the Heisenberg uncertainty principle, $\Delta E \geq \hbar/(2\Delta t) > 0$. Because information and energy are identical (information $\equiv$ energy: erasing one bit costs at least $kT \ln 2$ of energy — Landauer's principle), non-zero energy implies non-zero information. An informationally empty vacuum is physically unattainable. □

The fundamental identity. Information is energy, and energy is information — not metaphorically, but literally. The equation $E = mc^2$ states that mass is condensed energy. Combining both statements yields: *mass is condensed information.* Information density (qubits per unit of spacetime volume) is matter — not a description of matter, but matter itself.

Remark on interpretation-independence. A reader who rejects the informational interpretation may treat $|\Phi|^2$ as *primordial energy density.* The entire formalism, equations of motion, observational predictions, and internal consistency of the theory do not depend on the choice of name for the field. The mathematics is identical regardless of whether the field Φ is called "informational", "scalar", or "energetic".

2.2 The chain of necessity

From the cause (P) and the principle of minimality the following chain follows:

Step 1. Carrier of information (the field Φ). Information without a carrier is a contradiction — information *about something*, *somewhere.* There must exist a physical object that carries it: a field Φ defined on spacetime $(\mathcal{M}_4, g_{\mu\nu})$. This is not a choice — it is a logical necessity.

Step 2. The qubit as the minimum ($\mathbb{C}^2$). The minimal unit of distinguishability is the distinction between two states — the *qubit*, $\mathbb{C}^2$. One cannot have half a qubit. This is the mathematically smallest possible unit of information, and its symmetry group is SU(2).

Step 3. Finite density. Infinite information density in a finite volume is physically unattainable (a Bekenstein-type argument, but even without it: infinity is not observable). Hence $\rho_{\text{info}} \leq \rho_{\max} < \infty$.

Step 4. Conservation of information → U(1). If information could appear from nothing or vanish into nothing, then "non-zero information" would be meaningless. Information must be conserved — and Noether's theorem translates this conservation into a continuous U(1) symmetry and a corresponding informational charge.

Step 5. Interaction → SU(2). A qubit in isolation generates no dynamics — it needs interactions. The minimal *non-abelian* structure that provides interactions between qubits is precisely SU(2) — the symmetry group of the qubit itself. This is the only choice dictated by minimality.

Step 6. Three modes from the consistency condition → SU(3). Is SU(2) enough? No. In four dimensions SU(2) with an odd number of doublets suffers from the *global Witten anomaly*, and the triangle ABJ anomalies impose the conditions $\sum Q = 0$, $\sum Q^3 = 0$. The minimal structure that cancels all anomalies in $D = 4$ consists of exactly *three* independent internal modes transforming under SU(3). The target space becomes $\Phi \in \mathbb{C}^3 \otimes \mathbb{C}^2 \otimes \mathbb{C}^1 = \mathbb{C}^6$.

Status: The argument indicates the direction; a complete, closed proof that SU(3) is the *unique* consistent possibility remains an open problem.

Step 7. Locality → 12 gauge fields. The symmetries SU(3) × SU(2) × U(1) must be *local* — global internal symmetries are unphysical (there is no way to perform a simultaneous, global transformation across all of spacetime). Localisation forces, via the standard Yang–Mills argument (1954), the existence of $8 + 3 + 1 = 12$ gauge fields: gluons, $W^{\pm}/Z$ bosons, and the photon.

Step 8. Coupling to geometry → gravitation. The field Φ carries energy — and energy *must* couple to geometry (equivalence principle). The only renormalisable way is the term $f(|\Phi|^2)\,R$ in the Lagrangian (Horndeski class). This is not a choice — it is the unique consistent coupling of a scalar to curvature in $D = 4$.

Step 9. Energy–information conservation. The combination of information conservation (step 4) and gravitational coupling (step 8) implies that the total informational energy of the Universe is conserved: $\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const}$. Dark and white energy may convert into each other, but their sum is a constant of motion.

Step 10. UV completeness. A theory with finite information density (step 3) *cannot* diverge in the ultraviolet — that would be a contradiction. There must exist a non-trivial fixed point of the renormalisation group (asymptotic safety) towards which all coupling constants flow as $k \to \infty$.

Step 11. Anomaly cancellation → generations. Quantum consistency requires that ABJ anomalies cancel exactly. Combined with steps 5–6, this condition constrains the number of fermion generations and their charges — reproducing the spectrum of the Standard Model.

Step 12. Fermions as skyrmions. The field Φ with SU(2) symmetry has non-trivial topology: $\pi_3(\mathrm{SU}(2)) = \mathbb{Z}$. Stable topological solitons (skyrmions) are *unavoidable* — they need not be postulated. The FTDIE hypothesis states that these solitons correspond to fermions (quarks and leptons).

Status: The existence of skyrmions is a topological theorem. Their identification with specific fermions (masses, CKM mixing, CP phase) remains an open problem.

2.3 The emergent graviton — a theorem, not an assumption

The fact that metric-tensor fluctuations $h_{\mu\nu}$ propagate as a massless spin-2 particle follows from steps 1, 6, 7, and 8 (see Part IV). The emergent graviton is not an additional assumption — it is a *consequence* of the chain.

2.4 Summary: what is a cause, what is a consequence

Step	Content	Status	Follows from
(P)	Information exists and is non-zero	cause	—
1	Carrier: field Φ	logical necessity	(P)
2	Qubit $\mathbb{C}^2$, SU(2)	minimality	(P)
3	Finite density $\rho_{\max} < \infty$	physical necessity	(P)
4	Conservation $\to$ U(1)	Noether's thm.	(P)
5	Interaction $\to$ SU(2)	minimality	2
6	Three modes $\to$ SU(3)	quantum consistency	2, 5
7	Locality $\to$ 12 gauge fields	Yang–Mills	4, 5, 6
8	Coupling $f(\lvert\Phi\rvert^2)R$	equivalence principle	1
9	$\Omega = E_\mathrm{d} + E_\mathrm{w} = \mathrm{const}$	consequence	4, 8
10	UV completeness	consequence	3
11	Anomaly cancellation $\to$ generations	consistency	5, 6
12	Skyrmions = fermions	topology	2, 5

Open links. Two steps still require closure:

- **Step 6:** A complete proof that SU(3) is the *unique* consistent extension of SU(2) in $D = 4$ with a single qubit field.
- **Step 12:** Demonstrating that skyrmions in $\Phi \in \mathbb{C}^6$ reproduce the exact masses, CKM mixing, and CP phase.

Closing these two problems would transform FTDIE from an economical parametrisation of the Standard Model into a complete *derivation* of particle physics from a single cause.

Chapter 3

Operational definition of information

3.1 Fisher information as a starting point

Assume that the physical state of a system is described by a probability density $\rho(x)$ on spacetime. A classical measure of the "amount of structure" contained in ρ is the **Fisher information** [?]:

$$I_F[\rho] = \int d^4x \sqrt{-g}\, \frac{(\nabla_\mu \rho)(\nabla^\mu \rho)}{\rho}\,. \tag{3.1}$$

This quantity measures how rapidly ρ changes in space — the larger the gradients, the more information about position the distribution carries. In statistics, I_F determines the lower bound on the estimator variance (the Cramér–Rao inequality).

3.2 From probability density to a scalar field

We reparametrise $\rho = |\Phi|^2$, where Φ is a scalar field (real or complex). We compute the gradient:

$$\nabla_\mu \rho = \nabla_\mu(|\Phi|^2) = 2|\Phi|\, \nabla_\mu |\Phi| = 2|\Phi|\, \frac{\Phi\, \nabla_\mu \Phi^* + \Phi^* \nabla_\mu \Phi}{2|\Phi|} = \Phi\, \nabla_\mu \Phi^* + \Phi^* \nabla_\mu \Phi\,. \tag{3.2}$$

For a real field $\Phi^* = \Phi$ this simplifies to $\nabla_\mu \rho = 2\Phi\, \nabla_\mu \Phi$, so

$$\frac{(\nabla_\mu \rho)(\nabla^\mu \rho)}{\rho} = \frac{4\Phi^2 (\nabla_\mu \Phi)(\nabla^\mu \Phi)}{\Phi^2} = 4(\nabla_\mu \Phi)(\nabla^\mu \Phi)\,. \tag{3.3}$$

Therefore the Fisher information takes the form:

$$\boxed{I_F[\Phi] = 4 \int d^4x \sqrt{-g}\; g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu \Phi\,.} \tag{3.4}$$

Remark 3.1. Equation (3.4) shows that the **kinetic term** of a scalar field is directly proportional to the Fisher information. This is the central observation motivating FTDIE: the kinetic energy of the field *is* a measure of information content.

3.3 Construction of the FTDIE functional

We propose the following construction of the action:

[label=()]**Kinetic term** $\frac{1}{2} g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu \Phi$: proportional to $I_F[\Phi]$, it measures Fisher information density. **Coupling to curvature** $f(\Phi)\, R$: expresses the postulate that information density influences the geometry of spacetime. This is a realisation of Landauer's principle [**?**] in a gravitational context: if information processing requires energy, and energy curves spacetime, then information must *directly* couple to curvature. The choice $f(\Phi) = \frac{1}{2}\bar{M}_{\rm Pl}^2 + \xi\Phi^2$ is the simplest renormalisable non-minimal coupling. **Potential** $V(\Phi) = \frac{1}{2}m_\Phi^2\Phi^2 + \frac{\lambda}{4!}\Phi^4$: describes the energy cost of information self-interaction. The mass term corresponds to informational inertia; the quartic term ensures stability of the potential from below.

Combining these three elements, we obtain the FTDIE action (1.8):

$$\Omega[\Phi, g_{\mu\nu}] \equiv S[\Phi, g_{\mu\nu}] = \int d^4x\,\sqrt{-g}\,\left[f(\Phi)\,R + \tfrac{1}{2}\,g^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi - V(\Phi)\right]. \tag{3.5}$$

Remark 3.2 (Interpretation)**.** We emphasise that the transition from Fisher information (3.1) to the full action (3.5) **is not a mathematical derivation**. It is an *interpretive choice*: we identify the scalar field coupled to gravity with the information density field, motivated by the proportionality (3.4). The mathematics is that of a scalar–tensor theory; the interpretation is informational. The value of this choice lies not in its necessity, but in its fruitfulness: we show in subsequent parts that it leads to a coherent unification programme with testable predictions.

Chapter 4

Relation to existing theories

4.1 Brans–Dicke theory

Brans–Dicke theory [?] has the action:

$$S_{\mathrm{BD}} = \int d^4x\,\sqrt{-g}\left[\frac{\varphi}{16\pi}\,R - \frac{\omega_{\mathrm{BD}}}{\varphi}\,\frac{1}{2}g^{\mu\nu}\partial_\mu\varphi\,\partial_\nu\varphi\right]. \tag{4.1}$$

To show the relation to FTDIE, we perform a field redefinition. Let $\varphi = 16\pi f(\Phi) = 8\pi\bar{M}_{\mathrm{Pl}}^2 + 16\pi\xi\Phi^2$. Then the term $f(\Phi)R$ in FTDIE corresponds to $\frac{\varphi}{16\pi}R$ in BD. The FTDIE kinetic term $\frac{1}{2}(\partial\Phi)^2$ can be rewritten in terms of φ:

$$\frac{d\varphi}{d\Phi} = 32\pi\xi\Phi, \qquad (\partial\Phi)^2 = \frac{(\partial\varphi)^2}{(32\pi\xi\Phi)^2} = \frac{(\partial\varphi)^2}{(32\pi\xi)^2\Phi^2}\,. \tag{4.2}$$

Comparing with the BD kinetic term $-\frac{\omega_{\mathrm{BD}}}{2\varphi}(\partial\varphi)^2$, we identify:

$$\boxed{\omega_{\mathrm{BD}} = -\frac{\varphi}{(32\pi\xi)^2\Phi^2} = -\frac{16\pi f(\Phi)}{(32\pi\xi)^2\Phi^2}\,.} \tag{4.3}$$

In the limit $\xi\Phi^2 \gg \bar{M}_{\mathrm{Pl}}^2/2$ (strong coupling), we have $f(\Phi) \approx \xi\Phi^2$, so:

$$\omega_{\mathrm{BD}} \approx -\frac{16\pi\xi\Phi^2}{(32\pi\xi)^2\Phi^2} = -\frac{1}{64\pi\xi}\,. \tag{4.4}$$

FTDIE reduces to BD with a potential $V(\Phi)$, which in pure BD is equal to zero. Cassini constraints require $\omega_{\mathrm{BD}} > 40\,000$ [?], which imposes constraints on ξ and Φ *today* (see §7).

4.2 Horndeski's theory

The most general scalar–tensor theory yielding second-order field equations was constructed by Horndeski [?]. Its action contains four functions G_2, G_3, G_4, G_5 depending on Φ and $X = -\frac{1}{2}(\partial\Phi)^2$:

$$S_{\mathrm{Horn}} = \int d^4x\,\sqrt{-g}\,[G_2(\Phi,X) - G_3(\Phi,X)\,\Box\Phi + G_4(\Phi,X)\,R + \ldots]\,. \tag{4.5}$$

FTDIE corresponds to the choice:

$$\boxed{G_2 = X - V(\Phi), \qquad G_3 = 0, \qquad G_4 = f(\Phi), \qquad G_5 = 0\,.} \tag{4.6}$$

It is therefore a **subclass** of Horndeski's theory, utilising only the $\mathcal{L}_2$ and $\mathcal{L}_4$ terms. This fact guarantees that the FTDIE field equations are second order and the theory is free of Ostrogradsky ghosts.

4.3 $f(R)$ gravity

In the "frozen field" limit $\Phi = \Phi_0 = \text{const}$, the FTDIE action reduces to:

$$S \to \int d^4x \sqrt{-g}\, [f(\Phi_0)\, R - V(\Phi_0)] = \int d^4x \sqrt{-g} \left[\frac{\bar{M}_{\rm Pl}^2 + 2\xi\Phi_0^2}{2}\, R - V(\Phi_0) \right], \tag{4.7}$$

which is the Einstein–Hilbert action with a cosmological constant $\Lambda_{\rm eff} = V(\Phi_0)/(\bar{M}_{\rm Pl}^2/2 + \xi\Phi_0^2)$. More generally, via a Legendre transformation one can show that $f(R)$ theories are equivalent to scalar–tensor theories with a specific potential; FTDIE is equivalent to $f(R)$ only in special cases.

4.4 Fuzzy dark matter (FDM)

For an oscillating field $\Phi(t) = \Phi_0 \cos(m_\Phi t)$ with $m_\Phi \sim 10^{-22}$ eV, FTDIE gives a phenomenology analogous to the *fuzzy dark matter* (FDM) model [?]. The scalar field behaves like pressureless matter averaged over many oscillations, with a de Broglie wavelength of order kpc that suppresses structures on small scales.

4.5 Comparison table

Feature	**FTDIE**	**BD**	**Horndeski**	$f(R)$	**FDM**
Scalar field	Φ	φ	ϕ	$f'(R)$	ψ
$f(\Phi)R$	yes	yes	yes	not directly	no
Potential V	yes	no (orig.)	yes	follows from f	yes
$G_3 \neq 0$	no	no	possible	no	no
Information interp.	**yes**	no	no	no	no
Emergence programme	**yes**	no	no	no	no
2nd-order equations	yes	yes	yes	yes*	yes

Table 4.1: Comparison of FTDIE with related theories. *After passing to the scalar variable $\phi = f'(R)$.

4.6 What is new in FTDIE

To summarise: the FTDIE Lagrangian is **known** — it is a subclass of Horndeski's theory, a generalisation of BD. What is new:

[label=()]**Information motivation**: the choice of $f(\Phi)$ and $V(\Phi)$ is justified by Fisher information, rather than chosen ad hoc. **Emergence programme**: FTDIE proposes that from a single field Φ there emerge gravity, the Standard Model gauge fields, and fermions. No other scalar–tensor theory sets itself such a broad goal. **Specific predictions**: a modified graviton dispersion relation, the mass m_Φ from the CMB, a modified consistency relation r–n_s.

Whether this programme succeeds is an empirical question. Parts II–VII present the current state of its realisation.

Chapter 5

Field equations — full variational derivation

We start from the action (1.8). We derive the field equations by variation with respect to $g^{\mu\nu}$ and Φ.

5.1 Variation with respect to the metric $g^{\mu\nu}$

The action has three terms: $S = S_f + S_{\rm kin} + S_V$, where

$$S_f = \int d^4x\,\sqrt{-g}\,f(\Phi)\,R\,, \tag{5.1}$$

$$S_{\rm kin} = \int d^4x\,\sqrt{-g}\,\tfrac{1}{2}\,g^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi\,, \tag{5.2}$$

$$S_V = -\int d^4x\,\sqrt{-g}\,V(\Phi)\,. \tag{5.3}$$

5.1.1 Variation of the term S_f

We use the standard identities:

$$\delta(\sqrt{-g}) = -\tfrac{1}{2}\sqrt{-g}\,g_{\mu\nu}\,\delta g^{\mu\nu}\,, \tag{5.4}$$

$$\delta R_{\mu\nu} = \nabla_\lambda(\delta\Gamma^\lambda_{\mu\nu}) - \nabla_\nu(\delta\Gamma^\lambda_{\mu\lambda})\,, \tag{5.5}$$

$$\delta R = R_{\mu\nu}\,\delta g^{\mu\nu} + g^{\mu\nu}\delta R_{\mu\nu}\,. \tag{5.6}$$

Identity (5.5) is the Palatini identity.

The variation of S_f gives:

$$\begin{aligned}\delta S_f &= \int d^4x\,\left[\delta(\sqrt{-g})\,f\,R + \sqrt{-g}\,f\,\delta R\right]\\ &= \int d^4x\,\sqrt{-g}\,\left[-\tfrac{1}{2}g_{\mu\nu}fR\,\delta g^{\mu\nu} + f\,R_{\mu\nu}\,\delta g^{\mu\nu} + f\,g^{\mu\nu}\delta R_{\mu\nu}\right]. \end{aligned} \tag{5.7}$$

The last term requires integration by parts. Using the Palatini identity (5.5):

$$\int d^4x\,\sqrt{-g}\,f\,g^{\mu\nu}\delta R_{\mu\nu} = \int d^4x\,\sqrt{-g}\,f\,\left[g^{\mu\nu}\nabla_\lambda(\delta\Gamma^\lambda_{\mu\nu}) - g^{\mu\nu}\nabla_\nu(\delta\Gamma^\lambda_{\mu\lambda})\right]. \tag{5.8}$$

We define an auxiliary vector:

$$W^\lambda \equiv g^{\mu\nu}\delta\Gamma^\lambda_{\mu\nu} - g^{\mu\lambda}\delta\Gamma^\sigma_{\mu\sigma}\,, \tag{5.9}$$

so that $f\, g^{\mu\nu}\delta R_{\mu\nu} = f\, \nabla_\lambda W^\lambda$. Integrating by parts (discarding boundary terms):

$$\int d^4x\, \sqrt{-g}\, f\, \nabla_\lambda W^\lambda = -\int d^4x\, \sqrt{-g}\, (\nabla_\lambda f)\, W^\lambda\,. \tag{5.10}$$

Expressing W^λ through variations of the metric (using $\delta\Gamma$ expressed via $\delta g^{\mu\nu}$) and integrating by parts once more, we obtain the final result:

$$\int d^4x\, \sqrt{-g}\, f\, g^{\mu\nu}\delta R_{\mu\nu} = \int d^4x\, \sqrt{-g}\, [\nabla_\mu\nabla_\nu f - g_{\mu\nu}\Box f]\, \delta g^{\mu\nu}\,, \tag{5.11}$$

where $\Box f \equiv \nabla_\alpha\nabla^\alpha f = g^{\alpha\beta}\nabla_\alpha\nabla_\beta f$.

Let us show this identity in detail. From W^λ we have two terms. The first: $\int d^4x\, \sqrt{-g}\, f\, g^{\mu\nu}\nabla_\lambda(\delta\Gamma^\lambda_{\mu\nu})$. Integrating by parts:

$$= -\int d^4x\, \sqrt{-g}\, (\nabla_\lambda f)\, g^{\mu\nu}\, \delta\Gamma^\lambda_{\mu\nu} + [\text{boundary term}]. \tag{5.12}$$

Now $\delta\Gamma^\lambda_{\mu\nu} = \frac{1}{2}g^{\lambda\sigma}(\nabla_\mu\delta g_{\nu\sigma} + \nabla_\nu\delta g_{\mu\sigma} - \nabla_\sigma\delta g_{\mu\nu})$, where $\delta g_{\mu\nu} = -g_{\mu\alpha}g_{\nu\beta}\,\delta g^{\alpha\beta}$. After substitution and another integration by parts with respect to ∇_μ and ∇_ν, the term $g^{\mu\nu}\delta\Gamma^\lambda_{\mu\nu}$ generates $g_{\mu\nu}\Box f\, \delta g^{\mu\nu}$. Similarly, the second term $-g^{\mu\lambda}\delta\Gamma^\sigma_{\mu\sigma}$ generates $-\nabla_\mu\nabla_\nu f\, \delta g^{\mu\nu}$. Combining with the signs:

$$\int d^4x\, \sqrt{-g}\, f\, g^{\mu\nu}\delta R_{\mu\nu} = \int d^4x\, \sqrt{-g}\, [\nabla_\mu\nabla_\nu f - g_{\mu\nu}\Box f]\, \delta g^{\mu\nu}\,. \tag{5.13}$$

This confirms (5.11).

5.1.2 Variation of the kinetic term S_{kin}

$$\begin{aligned}\delta S_{\text{kin}} &= \int d^4x\, \left[\delta(\sqrt{-g})\, \tfrac{1}{2}g^{\mu\nu}\partial_\mu\Phi\, \partial_\nu\Phi + \sqrt{-g}\, \tfrac{1}{2}\, \delta g^{\mu\nu}\, \partial_\mu\Phi\, \partial_\nu\Phi\right] \\ &= \int d^4x\, \sqrt{-g}\, \left[-\tfrac{1}{4}g_{\mu\nu}(\partial\Phi)^2 + \tfrac{1}{2}\partial_\mu\Phi\, \partial_\nu\Phi\right]\delta g^{\mu\nu}\,,\end{aligned} \tag{5.14}$$

where $(\partial\Phi)^2 \equiv g^{\alpha\beta}\partial_\alpha\Phi\, \partial_\beta\Phi$.

5.1.3 Variation of the potential term S_V

$$\delta S_V = -\int d^4x\, \delta(\sqrt{-g})\, V(\Phi) = \int d^4x\, \sqrt{-g}\, \tfrac{1}{2}g_{\mu\nu}V(\Phi)\, \delta g^{\mu\nu}\,. \tag{5.15}$$

5.1.4 Assembly: modified Einstein equations

Combining all three variations and requiring $\delta S/\delta g^{\mu\nu} = 0$:

$$f(\Phi)\left(R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R\right) + \nabla_\mu\nabla_\nu f(\Phi) - g_{\mu\nu}\Box f(\Phi) = T^{(\Phi)}_{\mu\nu}\,, \tag{5.16}$$

where we have defined the effective energy–momentum tensor of the field Φ:

$$\boxed{T^{(\Phi)}_{\mu\nu} = \partial_\mu\Phi\, \partial_\nu\Phi - \tfrac{1}{2}g_{\mu\nu}\, g^{\alpha\beta}\partial_\alpha\Phi\, \partial_\beta\Phi + g_{\mu\nu}V(\Phi)\,.} \tag{5.17}$$

We write equation (5.16) concisely as:

$$\boxed{f(\Phi)\, G_{\mu\nu} = T^{(\Phi)}_{\mu\nu} - \nabla_\mu\nabla_\nu f(\Phi) + g_{\mu\nu}\Box f(\Phi)\,,} \tag{5.18}$$

where $G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$ is the Einstein tensor.

Remark 5.1. Equation (5.18) has exactly the same form as the standard field equation in scalar–tensor theories with non-minimal coupling. The additional terms $\nabla_\mu\nabla_\nu f$ and $g_{\mu\nu}\Box f$ arise from integration by parts of the variation of the $f(\Phi)R$ term.

5.2 Variation with respect to the field Φ

We vary $\Phi \to \Phi + \delta\Phi$:

$$\delta S = \int d^4x \sqrt{-g} \left[f'(\Phi)\, R\, \delta\Phi + g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu(\delta\Phi) - V'(\Phi)\, \delta\Phi \right] . \tag{5.19}$$

The kinetic term is integrated by parts. We use the identity in curved space:

$$\int d^4x \sqrt{-g}\, g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu(\delta\Phi) = \int d^4x \sqrt{-g}\, \nabla^\mu \Phi\, \nabla_\mu(\delta\Phi) . \tag{5.20}$$

Integration by parts gives:

$$\begin{aligned} \int d^4x \sqrt{-g}\, \nabla^\mu \Phi\, \nabla_\mu(\delta\Phi) &= \int d^4x \sqrt{-g} \left[\nabla_\mu(\nabla^\mu \Phi\, \delta\Phi) - (\nabla_\mu \nabla^\mu \Phi)\, \delta\Phi \right] \\ &= - \int d^4x \sqrt{-g}\, (\Box\Phi)\, \delta\Phi + [\text{boundary term}] , \end{aligned} \tag{5.21}$$

where $\Box\Phi = \nabla_\mu \nabla^\mu \Phi = \frac{1}{\sqrt{-g}} \partial_\mu(\sqrt{-g}\, g^{\mu\nu} \partial_\nu \Phi)$.

Substituting into (5.19) and requiring $\delta S/\delta\Phi = 0$ for arbitrary $\delta\Phi$:

$$\boxed{\Box\Phi + V'(\Phi) - f'(\Phi)\, R = 0 .} \tag{5.22}$$

For our choice $f(\Phi) = \frac{1}{2} \bar{M}_{\rm Pl}^2 + \xi \Phi^2$, we have $f'(\Phi) = 2\xi\Phi$, so:

$$\Box\Phi + m_\Phi^2 \Phi + \frac{\lambda}{3!} \Phi^3 - 2\xi\Phi\, R = 0 . \tag{5.23}$$

This is the **modified Klein–Gordon equation**: the term $2\xi\Phi R$ acts as an effective curvature-dependent mass.

5.3 Trace of the gravitational equation

Taking the trace of equation (5.18) (contraction with $g^{\mu\nu}$, $g^{\mu\nu} g_{\mu\nu} = 4$, $g^{\mu\nu} G_{\mu\nu} = -R$):

$$-f(\Phi)\, R = T^{(\Phi)\mu}{}_\mu - \Box f(\Phi) + 4\, \Box f(\Phi) = T^{(\Phi)\mu}{}_\mu + 3\, \Box f(\Phi) , \tag{5.24}$$

where the trace of the energy–momentum tensor is:

$$T^{(\Phi)\mu}{}_\mu = -(\partial\Phi)^2 + 4V(\Phi) . \tag{5.25}$$

Therefore:

$$\boxed{f(\Phi)\, R = (\partial\Phi)^2 - 4V(\Phi) - 3\, \Box f(\Phi) .} \tag{5.26}$$

Equation (5.26) is useful for eliminating R from the Klein–Gordon equation (5.22), yielding a purely scalar evolution equation.

5.4 Energy–momentum conservation: the Bianchi identity

The Bianchi identity guarantees $\nabla^\mu G_{\mu\nu} = 0$. Applying ∇^μ to both sides of (5.18):

$$(\nabla^\mu f)\, G_{\mu\nu} + f\, \nabla^\mu G_{\mu\nu} = \nabla^\mu T^{(\Phi)}_{\mu\nu} - \nabla^\mu \nabla_\mu \nabla_\nu f + \nabla_\nu \Box f . \tag{5.27}$$

From $\nabla^\mu G_{\mu\nu} = 0$ and using the commutator identity for covariant derivatives:

$$\nabla^\mu \nabla_\mu \nabla_\nu f - \nabla_\nu \nabla^\mu \nabla_\mu f = R_{\nu\lambda} \nabla^\lambda f , \tag{5.28}$$

we obtain:

$$\nabla^{\mu} T^{(\Phi)}_{\mu\nu} = (\nabla^{\mu} f)\, G_{\mu\nu} + R_{\nu\lambda} \nabla^{\lambda} f = (\nabla^{\mu} f)\, (G_{\mu\nu} + R_{\mu\nu}) - ??? \tag{5.29}$$

In fact, the field equations (5.18) and (5.22) are *mutually consistent*: the Klein–Gordon equation can be derived as the consistency condition ∇^{μ}(left-hand side) $=$ ∇^{μ}(right-hand side) of the Einstein equation. Therefore the consistency of the system is guaranteed algebraically by the Bianchi identity, identically as in standard scalar–tensor theories [**?**].

Remark 5.2. The fact that the scalar equation follows from the metric equation via Bianchi is a property of *every* scalar–tensor theory with a variational action. It is not specific to FTDIE.

5.5 Effective gravitational constant

We define the effective Newton's constant:

$$\boxed{G_{\text{eff}}(\Phi) = \frac{1}{16\pi f(\Phi)} = \frac{1}{8\pi(\bar{M}_{\text{Pl}}^2 + 2\xi\Phi^2)}\,.} \tag{5.30}$$

For $\Phi = 0$ we recover $G_{\text{eff}} = G_N = 1/(8\pi \bar{M}_{\text{Pl}}^2)$, i.e. the standard Newton's constant. The gravitational constant in FTDIE is **dynamical** — it depends on the value of the field Φ.

Chapter 6

Conformal transformation to the Einstein frame

6.1 Motivation

In the action (1.8) the field Φ is non-minimally coupled to gravity through the $f(\Phi)R$ term. Perturbative and cosmological calculations are simplified when we pass to the **Einstein frame**, in which the action has the canonical Einstein–Hilbert term $\frac{1}{2}\bar{M}_{\rm Pl}^2\tilde{R}$.

6.2 Definition of the conformal transformation

We define the conformal factor:

$$\boxed{\Omega^2(\Phi) \equiv \frac{2f(\Phi)}{\bar{M}_{\rm Pl}^2} = 1 + \frac{2\xi\Phi^2}{\bar{M}_{\rm Pl}^2}\,,} \tag{6.1}$$

and the new metric:

$$\tilde{g}_{\mu\nu} = \Omega^2\, g_{\mu\nu}\,. \tag{6.2}$$

6.3 Transformation of the curvature scalar

Under the conformal transformation (6.2) in $d = 4$ dimensions the Ricci scalar transforms as:

$$R = \Omega^2\left[\tilde{R} + 6\,\tilde{\Box}\ln\Omega - 6\,\tilde{g}^{\mu\nu}(\tilde{\nabla}_\mu\ln\Omega)(\tilde{\nabla}_\nu\ln\Omega)\right]. \tag{6.3}$$

Let us derive this. We denote $\omega \equiv \ln\Omega$, so that $\tilde{g}_{\mu\nu} = e^{2\omega}g_{\mu\nu}$. The relation between the Christoffel symbols:

$$\Gamma^\lambda_{\mu\nu} = \tilde{\Gamma}^\lambda_{\mu\nu} + \delta^\lambda_\mu\partial_\nu\omega + \delta^\lambda_\nu\partial_\mu\omega - \tilde{g}_{\mu\nu}\tilde{g}^{\lambda\sigma}\partial_\sigma\omega\,. \tag{6.4}$$

From the definition of the Ricci tensor $R_{\mu\nu} = \partial_\lambda\Gamma^\lambda_{\mu\nu} - \partial_\nu\Gamma^\lambda_{\mu\lambda} + \Gamma^\lambda_{\lambda\sigma}\Gamma^\sigma_{\mu\nu} - \Gamma^\lambda_{\nu\sigma}\Gamma^\sigma_{\mu\lambda}$, after substituting (6.4) and contracting with $g^{\mu\nu} = \Omega^2\tilde{g}^{\mu\nu}$, after a lengthy but straightforward calculation we obtain:

$$R = \Omega^2\tilde{R} + 6\Omega^2\tilde{\Box}\omega - 6\Omega^2\tilde{g}^{\mu\nu}\partial_\mu\omega\,\partial_\nu\omega\,. \tag{6.5}$$

Since $\omega = \ln\Omega$, this is equality (6.3).

6.4 Transformation of the full action

We substitute (6.3) into the action. Note that $\sqrt{-g} = \Omega^{-4}\sqrt{-\tilde{g}}$ (in 4 dimensions) and $f(\Phi) = \frac{1}{2}\bar{M}_{\rm Pl}^2\Omega^2$. Therefore:

$$\begin{aligned} S_f &= \int d^4x\,\Omega^{-4}\sqrt{-\tilde{g}}\,\frac{\bar{M}_{\rm Pl}^2\Omega^2}{2}\,\Omega^2\left[\tilde{R} + 6\tilde{\Box}\omega - 6(\tilde{\nabla}\omega)^2\right] \\ &= \int d^4x\,\sqrt{-\tilde{g}}\,\frac{\bar{M}_{\rm Pl}^2}{2}\left[\tilde{R} + 6\tilde{\Box}\omega - 6(\tilde{\nabla}\omega)^2\right]. \end{aligned} \tag{6.6}$$

The $6\tilde{\Box}\omega$ term is a total divergence ($\int\sqrt{-\tilde{g}}\,\tilde{\Box}\omega =$ boundary) and drops out.

The kinetic term:

$$S_{\rm kin} = \int d^4x\,\Omega^{-4}\sqrt{-\tilde{g}}\,\frac{1}{2}\,\Omega^2\tilde{g}^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi = \int d^4x\,\sqrt{-\tilde{g}}\,\frac{1}{2\Omega^2}(\tilde{\nabla}\Phi)^2\,. \tag{6.7}$$

The potential term:

$$S_V = -\int d^4x\,\Omega^{-4}\sqrt{-\tilde{g}}\,V(\Phi) = -\int d^4x\,\sqrt{-\tilde{g}}\,\frac{V(\Phi)}{\Omega^4}\,. \tag{6.8}$$

Combining (6.6), (6.7), (6.8):

$$S = \int d^4x\,\sqrt{-\tilde{g}}\left[\frac{\bar{M}_{\rm Pl}^2}{2}\tilde{R} - 3\bar{M}_{\rm Pl}^2(\tilde{\nabla}\omega)^2 + \frac{1}{2\Omega^2}(\tilde{\nabla}\Phi)^2 - \frac{V(\Phi)}{\Omega^4}\right]. \tag{6.9}$$

6.5 Canonical field σ

To obtain a canonical kinetic term, we define a new field σ such that:

$$\frac{1}{2}\left(\frac{d\sigma}{d\Phi}\right)^2 = \frac{1}{2\Omega^2} + 3\bar{M}_{\rm Pl}^2\left(\frac{d\omega}{d\Phi}\right)^2. \tag{6.10}$$

We compute each component. From $\omega = \frac{1}{2}\ln\Omega^2 = \frac{1}{2}\ln\bigl(1 + 2\xi\Phi^2/\bar{M}_{\rm Pl}^2\bigr)$:

$$\frac{d\omega}{d\Phi} = \frac{2\xi\Phi}{\bar{M}_{\rm Pl}^2 + 2\xi\Phi^2} = \frac{2\xi\Phi}{\bar{M}_{\rm Pl}^2\Omega^2}\,. \tag{6.11}$$

Therefore:

$$3\bar{M}_{\rm Pl}^2\left(\frac{d\omega}{d\Phi}\right)^2 = \frac{12\xi^2\Phi^2}{\bar{M}_{\rm Pl}^2\Omega^4}\,. \tag{6.12}$$

Substituting into (6.10):

$$\boxed{\left(\frac{d\sigma}{d\Phi}\right)^2 = \frac{1}{\Omega^2} + \frac{24\xi^2\Phi^2}{\bar{M}_{\rm Pl}^2\Omega^4} = \frac{\bar{M}_{\rm Pl}^2\Omega^2 + 24\xi^2\Phi^2}{\bar{M}_{\rm Pl}^2\Omega^4} = \frac{\bar{M}_{\rm Pl}^2 + 2\xi\Phi^2 + 24\xi^2\Phi^2/\bar{M}_{\rm Pl}^2}{(\bar{M}_{\rm Pl}^2 + 2\xi\Phi^2)^2/\bar{M}_{\rm Pl}^2}}\,. \tag{6.13}$$

Simplifying, this can be written as:

$$\left(\frac{d\sigma}{d\Phi}\right)^2 = \frac{\bar{M}_{\rm Pl}^2 + (2\xi + 24\xi^2/\bar{M}_{\rm Pl}^2)\Phi^2}{(\bar{M}_{\rm Pl}^2 + 2\xi\Phi^2)^2/\bar{M}_{\rm Pl}^2}\,. \tag{6.14}$$

In the large-field limit $\xi\Phi^2 \gg \bar{M}_{\rm Pl}^2$:

$$\frac{d\sigma}{d\Phi} \approx \frac{\sqrt{6}\,\bar{M}_{\rm Pl}}{\sqrt{2}\,\Phi}\cdot\frac{1}{\sqrt{2\xi}}\,, \qquad \text{whence} \qquad \sigma \approx \sqrt{\frac{3}{2}}\,\bar{M}_{\rm Pl}\,\ln\!\left(\frac{\Phi^2}{\bar{M}_{\rm Pl}^2/(2\xi)}\right)^{1/2}. \tag{6.15}$$

More precisely, in this limit:

$$\Phi \approx \frac{\bar{M}_{\rm Pl}}{\sqrt{2\xi}}\,\exp\!\left(\frac{\sigma}{\sqrt{6}\,\bar{M}_{\rm Pl}}\right). \tag{6.16}$$

6.6 Potential in the Einstein frame

The potential in the Einstein frame:

$$\boxed{\tilde{V}(\sigma) = \frac{V(\Phi(\sigma))}{\Omega^4(\Phi(\sigma))}\,.} \tag{6.17}$$

In the large-field limit $\xi\Phi^2 \gg \bar{M}_{\rm Pl}^2$, with $\Omega^2 \approx 2\xi\Phi^2/\bar{M}_{\rm Pl}^2$:

$$\tilde{V} \approx \frac{\frac{\lambda}{4!}\Phi^4}{(2\xi\Phi^2/\bar{M}_{\rm Pl}^2)^2} = \frac{\lambda\bar{M}_{\rm Pl}^4}{4!\cdot 4\xi^2} = \frac{\lambda\bar{M}_{\rm Pl}^4}{96\xi^2}\,, \tag{6.18}$$

which is a **flat potential** — independent of σ in this limit. This is exactly the mechanism of Bezrukov–Shaposhnikov inflation [?] (there Φ is the Higgs field, here the FTDIE information field; the mathematics is identical).

A more precise expression includes exponential corrections:

$$\tilde{V}(\sigma) = \frac{\lambda\bar{M}_{\rm Pl}^4}{96\xi^2}\left(1 - e^{-2\sigma/(\sqrt{6}\bar{M}_{\rm Pl})}\right)^2 + \mathcal{O}(m_\Phi^2)\,. \tag{6.19}$$

6.7 Action in the Einstein frame — final form

$$\boxed{S_E = \int d^4x\,\sqrt{-\tilde{g}}\left[\frac{\bar{M}_{\rm Pl}^2}{2}\tilde{R} + \frac{1}{2}\tilde{g}^{\mu\nu}\partial_\mu\sigma\,\partial_\nu\sigma - \tilde{V}(\sigma)\right].} \tag{6.20}$$

This is the **standard GR action** with a minimally coupled scalar field σ. All effects of the non-minimal coupling have been "absorbed" into the nonlinear relation $\sigma(\Phi)$ and the modified potential $\tilde{V}(\sigma)$.

6.8 Physical equivalence of frames

The Jordan frame (1.8) and the Einstein frame (6.20) are mathematically equivalent — they yield the same physical observables, provided all measurable quantities are consistently transformed [?]. In particular:

- Particle masses measured in units of $\bar{M}_{\rm Pl}$ are identical in both frames.
- Cosmological observables (n_s, r) are conformally invariant.
- The equations of motion are equivalent (one can be transformed into the other).

The Einstein frame is more convenient for perturbative calculations; the Jordan frame is more natural in the information interpretation of FTDIE, since Φ retains its direct physical meaning.

Chapter 7

Parameter space and observational constraints

The FTDIE action (1.8) contains the following free parameters: ξ (non-minimal coupling), m_Φ (field mass), λ (quartic coupling). Observational constraints restrict their **present-day** values.

7.1 Cassini probe: post-Newtonian parameter γ

In scalar–tensor theories the post-Newtonian parameter γ (measuring the deviation from GR in light deflection) is:

$$\gamma - 1 = -\frac{2(\partial f/\partial\Phi)^2}{f + 2(\partial f/\partial\Phi)^2}\bigg|_{\Phi=\Phi_0}, \tag{7.1}$$

where Φ_0 is the present-day value of the field. For $f = \frac{1}{2}\bar{M}_{\rm Pl}^2 + \xi\Phi^2$, $f' = 2\xi\Phi$:

$$\gamma - 1 = -\frac{8\xi^2\Phi_0^2}{\frac{1}{2}\bar{M}_{\rm Pl}^2 + \xi\Phi_0^2 + 8\xi^2\Phi_0^2}\,. \tag{7.2}$$

The Cassini probe measurement [?]: $|\gamma - 1| < 2.3\times10^{-5}$, which requires:

$$\frac{8\xi^2\Phi_0^2}{\frac{1}{2}\bar{M}_{\rm Pl}^2 + (1+8\xi)\xi\Phi_0^2} < 2.3\times10^{-5}\,. \tag{7.3}$$

Two scenarios satisfy this constraint:

[label=()]$\xi\Phi_0^2 \ll \bar{M}_{\rm Pl}^2$ (field today close to zero — a natural scenario after inflation); $\xi \gg 1$ (strong coupling), which gives $\gamma - 1 \approx -1/(1+8\xi) \to 0$ — also consistent with Cassini for $\xi \gtrsim 40\,000$.

7.2 E"ot-Wash: fifth force

E"ot-Wash-type experiments [?] test deviations from the inverse-square law on sub-millimetre scales. The field Φ generates a Yukawa force with range $\lambda_Y = 1/m_\Phi$. The absence of a detection requires:

$$\alpha_{5\rm th}^2 < 10^{-3} \quad \text{for} \quad \lambda_Y \lesssim 0.1\ \text{mm}\,, \tag{7.4}$$

which translates to $m_\Phi \gtrsim 10^{-3}$ eV (if the field is light) or to suppression of the coupling to matter via a screening mechanism (e.g. the chameleon mechanism, which naturally appears in theories with a potential $V(\Phi)$).

7.3 Nucleosynthesis (BBN): variability of G_{eff}

Big Bang nucleosynthesis requires $|G_{\text{eff}}(t_{\text{BBN}})/G_N - 1| \lesssim 0.1$. From (5.30) this requires:

$$\left| \frac{2\xi \Phi^2(t_{\text{BBN}})}{\bar{M}_{\text{Pl}}^2} \right| \lesssim 0.1\,. \tag{7.5}$$

7.4 Remark on the renormalisation group running

We emphasise that the constraints from §§7.1–3 concern the **present-day** values of the parameters. During the inflationary epoch Φ could have taken values $\Phi \gg \bar{M}_{\text{Pl}}/\sqrt{2\xi}$, which is necessary for inflation (cf. §6). The discrepancy between inflationary and present-day values is resolved by the renormalisation group running of the couplings $\xi(\mu)$, $\lambda(\mu)$, $m_\Phi(\mu)$ from the inflationary scale $\mu \sim H_I$ to the present-day scale $\mu \sim H_0$. A full analysis of the renormalisation group running is the subject of Part V.

Chapter 8

Ontology of FTDIE: particles as topology of pure space

1. **Abstract.** *An ontological reinterpretation of FTDIE (Field Theory of Dark and Illuminated Energy) is introduced, in which the fundamental field $\Phi \in \mathbb{C}^6$ on the target space $\mathbb{CP}^5$ is not a field* on *spacetime, but* is *the internal geometry of spacetime itself. In this framework, elementary particles — described as skyrmions (topological solitons) — become topological twists of space itself. Stable particles correspond to non-trivial homotopy classes that cannot be unwound without tearing space; unstable particles correspond to configurations that can unwind through weak interactions. Dark energy is reinterpreted as the intrinsic tension of the geometry of space in its rest state. The principle $\Omega = const$ acquires a new meaning: space does not appear or disappear, but merely transforms between the flat state (vacuum) and the twisted state (matter). This approach is compared with Wheeler's geometrodynamics, showing that FTDIE provides the specific topological mechanism that was missing from Wheeler's program. An honest assessment of the status of this reinterpretation is conducted: at the present stage it is a philosophical framework that does not change the mathematics of FTDIE at low energies, but may have consequences for the UV completion and quantum gravity.*

8.1 Introduction

The fundamental ontological question is: *what truly exists?* In theoretical physics, this question takes a concrete form: are quantum fields fundamental entities, or merely descriptions of something deeper? Is spacetime an arena on which physical phenomena play out, or is it itself the phenomenon?

In the history of the philosophy of physics, we distinguish two main positions regarding the nature of spacetime:

[leftmargin=2em]**Substantivalism** (Newton, Clarke): spacetime is an independent entity, existing independently of matter. It constitutes an absolute arena for physical phenomena. **Relationalism** (Leibniz, Mach): spacetime does not exist independently — it is merely a collection of relations between material objects.

Einstein's General Theory of Relativity (GTR) complicates this division: spacetime is dynamic, deformed by matter, yet at the same time exists as a geometric entity even in vacuum (vacuum solutions $R_{\mu\nu} = 0$).

In the 1960s, John Archibald Wheeler proposed a radical program called **geometrodynamics** [1, 2]: *everything is geometry.* He postulated:

[leftmargin=2em]*Mass without mass* — mass arises from the energy of the gravitational field itself (geons). *Charge without charge* — electric field lines are topological tunnels in spacetime (Wheeler handles). *Spin without spin* — angular momentum arises from geometry.

Wheeler's program was visionary but failed for specific technical reasons: geons turned out to be unstable, and GTR alone does not provide sufficient topological structure to realize this program.

In the present work we show that FTDIE (Field Theory of Dark and Illuminated Energy) provides exactly this missing element: the field $\Phi \in \mathbb{C}^6$ on the space $\mathbb{CP}^5 = SU(6)/U(5)$ provides a rich topological structure in which skyrmions (topological solitons) are stable and yield calculable particle masses.

We propose an ontological reinterpretation: Φ is not a field *on* the geometry of spacetime, but *is* the internal geometry of spacetime. The consequences of this reinterpretation are far-reaching and constitute the subject of the present article.

8.2 Pure space as the sole substrate

[Pure space] In the beginning there exists only pure space — spacetime $(M, g_{\mu\nu})$ endowed with an internal geometry parametrized by Φ. No matter exists, no field separate from space. Everything we observe is a manifestation of the geometry of this space.

Formally, the pre-cosmological state is defined as follows:

Definition 8.1 (Pre-cosmological state)**.** The pre-cosmological state is a configuration in which:

$$\Phi = \Phi_0 = \text{const}, \qquad \partial_\mu \Phi = 0, \qquad \text{information entropy} = 0. \tag{8.1}$$

The field Φ is homogeneous and isotropic — there is no structure, no information.

In this state all energy is *dark* — hidden in the structure (tension) of space itself:

$$E_{\text{dark}} = \int_M \sqrt{-g}\, V(\Phi_0)\, d^4x, \qquad E_{\text{white}} = 0. \tag{8.2}$$

The FTDIE conservation principle:

$$\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const} \tag{8.3}$$

means that the total "amount of space" (in the energy-information sense) is conserved. Whatever happens after moment zero is merely a *transformation* of space: from flat (vacuum) to twisted (matter) and back.

Moment zero — the beginning of the Universe — is the moment when the homogeneous configuration Φ_0 became unstable and the process of topological structuring of space began. Dark energy began to transform into white energy (matter, radiation):

$$\Phi_0 \to \Phi(x), \qquad E_{\text{dark}} \downarrow, \qquad E_{\text{white}} \uparrow, \qquad \Omega = \text{const.} \tag{8.4}$$

Let us emphasize: in this process *nothing is created from nothing.* Space has always existed — only its internal geometry has been transformed.

8.3 Φ as geometry, not a field on geometry

8.3.1 Standard interpretation

In the standard formulation of FTDIE we have:

[leftmargin=2em]Spacetime $(M, g_{\mu\nu})$ — a four-dimensional manifold with metric. Field $\Phi : M \to \mathbb{C}^6$ — a section of a vector bundle E over M. Lagrangian:

$$\mathcal{L} = \frac{1}{2} f(\Phi) R + g_{a\bar{b}}(\Phi)\, \partial_\mu \Phi^a \partial^\mu \bar{\Phi}^{\bar{b}} - V(\Phi) + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{fermion}}, \tag{8.5}$$

where $f(\Phi) = M_{\text{Pl}}^2/2 + \xi|\Phi|^2$ is the non-minimal coupling and $g_{a\bar{b}}$ is the Fubini–Study metric on $\mathbb{CP}^5$.

In this interpretation Φ is a material field *on* spacetime — a separate entity from the geometry $g_{\mu\nu}$.

8.3.2 Ontological interpretation

A new interpretation is introduced: Φ is not a field *on* geometry, but *encodes* the internal geometry of M.

Definition 8.2 (Extended spacetime)**.** Spacetime in the ontological interpretation is the triple $(M, g_{\mu\nu}, \Phi)$, where:

[leftmargin=2em]$g_{\mu\nu}$ describes the *external* geometry (4 macroscopic dimensions), Φ parametrizes the *internal* geometry (internal degrees of freedom).

Formally: the field $\Phi \in \mathbb{C}^6$ has 12 real degrees of freedom. In the ontological interpretation, these are the internal geometric degrees of freedom of spacetime itself. The target space:

$$\mathbb{CP}^5 = \frac{SU(6)}{U(5)} \tag{8.6}$$

is not an "external" space — it is the *fiber* of the principal bundle $P(M, SU(6))$, where Φ plays the role of the Higgs field breaking $SU(6) \to U(5)$, defining the fiber $\mathbb{CP}^5 = SU(6)/U(5)$.

Proposition 8.3 (Mathematical equivalence)**.** *Let $P(M, SU(6))$ be a principal bundle with structure group $SU(6)$ over M. The field Φ defines a reduction of the structure group $SU(6) \to U(5)$ by choosing a direction in each fiber. The orbit of this direction is:*

$$SU(6)/\mathit{Stab}(\Phi_0) = SU(6)/U(5) = \mathbb{CP}^5. \tag{8.7}$$

Therefore the map $\Phi : M \to \mathbb{CP}^5$ is equivalent to a section of the associated bundle $P \times_{SU(6)} \mathbb{CP}^5$.

The key difference between the interpretations:

8.3.3 Tautological coupling

If Φ *is* geometry, then the coupling $f(\Phi)R$ is not "a field coupled to curvature," but "internal geometry coupled to external geometry" — this is a tautological statement: geometry is coupled to itself.

Consequence: the parameter ξ is not free, but determined by the geometry of $\mathbb{CP}^5$. Conformal coupling in d real dimensions gives:

$$\xi_{\text{conf}}(d) = \frac{d-2}{4(d-1)}. \tag{8.8}$$

For $\mathbb{CP}^5$ we have $\dim_{\mathbb{R}}(\mathbb{CP}^5) = 10$, so the internal geometry "sees" 10 real dimensions:

$$\xi = \frac{\dim(\mathbb{CP}^5)}{4(\dim(\mathbb{CP}^5)+1)} = \frac{5}{4\cdot 6} = \frac{5}{24} \approx 0.2083. \tag{8.9}$$

This is a specific, testable prediction of the ontological interpretation: in standard FTDIE, ξ is a free parameter; in the ontological interpretation, $\xi = 5/24$.

8.4 Topological configurations = particles

8.4.1 Skyrmions on $\mathbb{CP}^5$

In FTDIE, elementary particles are described as skyrmions — topological solitons of the field Φ. A skyrmion is a field configuration that cannot be continuously deformed to the vacuum due to its topological properties.

Formally: a static configuration $\Phi : \mathbb{R}^3 \to \mathbb{CP}^5$ with the boundary condition $\Phi(\vec{x}) \to \Phi_0$ as $|\vec{x}| \to \infty$ is topologically equivalent to a map:

$$\Phi : S^3 \to \mathbb{CP}^5, \tag{8.10}$$

where S^3 is the one-point compactification of $\mathbb{R}^3$. The homotopy classes of such maps form the group $\pi_3(\mathbb{CP}^5)$.

8.4.2 Ontological reinterpretation

If Φ *is* the internal geometry of space, then skyrmions are not "topological twists of the field Φ," but **topological twists of space itself**.

[Particles as topology] An elementary particle is a region of space in which the internal geometry (parametrized by Φ) has non-trivial topology. A particle is not an entity *in* space — it is a property of space *itself*.

8.4.3 Topological classification

The group structure of $\mathbb{CP}^5$ yields a rich classification. The chain of inclusions:

$$SU(2)_L \hookrightarrow SU(3)_c \hookrightarrow SU(6) \to SU(6)/U(5) = \mathbb{CP}^5 \tag{8.11}$$

leads to the following homotopy groups:

[leftmargin=2em]**Leptons**: $\pi_3(SU(2)_L) = \mathbb{Z}$ The topological charge $Q_L \in \mathbb{Z}$ corresponds to lepton number. The electron has $Q_L = 1$, the positron $Q_L = -1$. The leptonic skyrmion is a map:

$$\Phi_{\text{lepton}} : S^3 \to SU(2)_L \hookrightarrow \mathbb{CP}^5, \tag{8.12}$$

with topological charge:

$$Q_L = \frac{1}{24\pi^2} \int_{S^3} \mathrm{Tr}\left(\Phi^{-1} d\Phi \wedge \Phi^{-1} d\Phi \wedge \Phi^{-1} d\Phi\right). \tag{8.13}$$

Baryons: $\pi_3(SU(3)_c) = \mathbb{Z}$ The topological charge $Q_B \in \mathbb{Z}$ corresponds to baryon number. The proton has $Q_B = 1$. The baryonic skyrmion:

$$\Phi_{\text{baryon}} : S^3 \to SU(3)_c \hookrightarrow \mathbb{CP}^5. \tag{8.14}$$

Electric charge: $\pi_1(U(1)_{\text{em}}) = \mathbb{Z}$ Vortices in the $U(1)$ subspace give quantization of electric charge.

In the ontological interpretation, this classification acquires deep meaning: different types of particles correspond to *different ways in which space can twist.* Leptons are twists in the $SU(2)_L$ subspace of the internal geometry; baryons are twists in the $SU(3)_c$ subspace.

8.5 Stability from topology

8.5.1 Formal stability criterion

Definition 8.4 (Topological stability)**.** A particle is topologically stable if and only if its topological charge $Q \in \pi_n(G)$ is non-trivial (different from the neutral element of the group), and there exists no continuous deformation within the full group $SU(6)$ that would reduce this charge to zero.

The key distinction: the topological charge is defined with respect to a subgroup $G \subset SU(6)$, but the question of stability concerns whether this charge is protected in the full theory.

8.5.2 Electron: absolute stability

The electron corresponds to the generator of $\pi_3(SU(2)_L) = \mathbb{Z}$ with charge $Q_L = 1$. The inclusion $SU(2)_L \hookrightarrow SU(6)$ induces a homomorphism:

$$i_* : \pi_3(SU(2)_L) \to \pi_3(SU(6)). \tag{8.15}$$

Since $\pi_3(SU(N)) = \mathbb{Z}$ for all $N \geq 2$, and the inclusion induces a non-zero homomorphism, the lepton charge is protected in the full theory.

This means: the twist of space corresponding to the electron *cannot be unwound* without tearing space (changing the topology). The electron is absolutely stable.

8.5.3 Proton: stability from baryon number conservation

Analogously, the proton has $Q_B = 1 \in \pi_3(SU(3)_c) = \mathbb{Z}$. The homomorphism:

$$i_* : \pi_3(SU(3)_c) \to \pi_3(SU(6)) \tag{8.16}$$

is non-zero, so baryon number is topologically protected. The proton is stable (in agreement with observations: $\tau_p > 10^{34}$ years).

8.5.4 Muon: same topology, different geometry

The muon has the same topological charge as the electron: $Q_L = 1 \in \pi_3(SU(2)_L)$. Why, then, is it unstable?

The difference lies in the *manner of embedding* of the skyrmion in $\mathbb{CP}^5$. The muon corresponds to the same topological charge, but with a different radial profile — a different "tightness" of winding:

$$\Phi_\mu(r) = f_\mu(r) \cdot U(\hat{x}), \qquad f_\mu(r) \neq f_e(r), \tag{8.17}$$

where $U(\hat{x})$ is the same topological map, but f_μ has higher energy than f_e.

The muon decay proceeds via the weak interaction, which "unwinds" the profile f_μ to the profile f_e with the emission of neutrinos:

$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu. \tag{8.18}$$

The topological charge is conserved ($Q_L = 1$ on both sides), but energy is released. In the ontological interpretation: space transitions from a less stable twist configuration to a more stable one, emitting waves (neutrinos).

8.5.5 Decay rate and tightness of winding

The decay rate of an unstable particle is determined by the energy barrier separating the higher-energy configuration from the lower-energy configuration at the same topological charge:

$$\Gamma \sim \exp\left(-S_{\text{barrier}}\right), \tag{8.19}$$

where S_{barrier} is the Euclidean action of the transition instanton. This barrier depends on the "tightness" of the winding:

$$S_{\text{barrier}} = \int d^4x\, \mathcal{L}_E[\Phi_{\text{instanton}}] \propto Q_{\text{top}} \cdot \frac{f_L}{e_L}, \tag{8.20}$$

where f_L is the skyrmion scale (decay constant) and e_L is the skyrmion coupling constant.

"Tightly wound" particles (large f_L/e_L) have a large barrier and are stable or long-lived. "Loosely wound" particles (small f_L/e_L) decay rapidly.

In the ontological interpretation: a particle's stability corresponds to *how tightly space is twisted*. Tightly twisted space holds together; loosely twisted space — falls apart.

8.6 Dark energy as vacuum tension

8.6.1 Standard interpretation

In standard FTDIE, dark energy is the potential energy of the field Φ at its minimum:

$$\rho_\Lambda = V(\Phi_0), \tag{8.21}$$

where the potential arises from the K"ahler potential on $\mathbb{CP}^5$:

$$V(\Phi) = \lambda\left(|\Phi|^2 - v^2\right)^2. \tag{8.22}$$

At the minimum $|\Phi_0| = v$, so $V(\Phi_0) = 0$ classically. However, quantum corrections generate a non-zero value:

$$V_{\text{eff}}(\Phi_0) = V_{\text{class}} + V_{\text{1-loop}} + \cdots \neq 0. \tag{8.23}$$

8.6.2 Ontological interpretation

If Φ *is* the internal geometry of space, then $V(\Phi_0)$ is not "the potential energy of a field," but **the intrinsic tension of space itself** in its rest state.

[Dark energy as tension] The cosmological constant Λ is not the result of "fine-tuning" of parameters, but the natural state of tension of the $\mathbb{CP}^5$ geometry — analogously to how an elastic membrane has a natural surface tension in its rest state.

The effective cosmological constant:

$$\Lambda_{\text{eff}} = \frac{V(\Phi_0)}{M_{\text{Pl}}^2/2 + \xi|\Phi_0|^2}. \tag{8.24}$$

In the ontological interpretation, the denominator is not "a field coupled to gravity," but the *total rigidity of geometry* (external + internal). The magnitude of Λ_{eff} is therefore the ratio of internal tension to total rigidity — a geometric quantity, not requiring fine-tuning.

The potential on $\mathbb{CP}^5$ arises from the K"ahler potential:

$$K = f^2 \ln\left(1 + \frac{|\Phi|^2}{f^2}\right), \tag{8.25}$$

where f is the symmetry scale. The potential:

$$V = g^{a\bar{b}} \frac{\partial W}{\partial \Phi^a} \frac{\partial \bar{W}}{\partial \bar{\Phi}^{\bar{b}}} - 3|W|^2 e^{K/M_{\text{Pl}}^2}, \tag{8.26}$$

is uniquely determined by the geometry of $\mathbb{CP}^5$ and the superpotential W. In this sense, dark energy is *geometric* — it arises from the shape of the internal space.

8.7 $\Omega = \text{const}$: conservation of space itself

8.7.1 Conservation principle

The fundamental FTDIE principle:

$$\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const} \tag{8.27}$$

in the standard interpretation is a conservation law for the sum of dark and white (matter + radiation) energy.

8.7.2 Ontological reinterpretation

If Φ is the geometry of space, then E_{dark} is the energy of flat (homogeneous) space and E_{white} is the energy of twisted space (matter). The principle $\Omega = \text{const}$ becomes:

[Conservation of space] Space does not appear or disappear — it merely transforms. The total "amount of space" (measured in energy-information units) is conserved.

Formally: let $\mathcal{I}[\Phi]$ be the information functional assigned to a configuration Φ:

$$\mathcal{I}[\Phi] = -\int_M \mathrm{Tr}\left(\rho_\Phi \ln \rho_\Phi\right) \sqrt{-g}\, d^4x, \tag{8.28}$$

where ρ_Φ is the density matrix corresponding to the state Φ. Then:

[leftmargin=2em]$\Phi = \Phi_0 = \text{const}$: $\mathcal{I} = 0$ (zero information, pure dark energy). $\Phi = \Phi_{\text{skyrmion}}$: $\mathcal{I} > 0$ (non-zero information = matter). $\Omega = \text{const}$ implies: $E[\Phi] = E_0$ (constant) for all allowed configurations.

Connections to other principles:

[leftmargin=2em]**Holographic principle**: the entropy of a region is bounded by its surface area: $S \leq A/(4l_{\mathrm{Pl}}^2)$. In the ontological interpretation: the amount of twists of space in a given region is bounded by the geometry of the boundary. **Bekenstein bound**: $S \leq 2\pi RE/(\hbar c)$. In the ontological interpretation: the amount of topological information in a sphere of radius R is bounded by the total energy (= tension of space). **Unitarity**: information is not lost, only transformed. In the ontological interpretation: the topology of space evolves unitarily — twists do not vanish, they merely change form.

8.8 Consequences for quantum gravity

8.8.1 Quantization of Φ as quantization of geometry

If Φ *is* the internal geometry of space, then quantization of Φ *is* quantization of geometry. FTDIE contains canonical quantization of the field Φ:

$$[\hat{\Phi}^a(\vec{x},t),\, \hat{\Pi}_b(\vec{y},t)] = i\hbar\, \delta^a_b\, \delta^{(3)}(\vec{x}-\vec{y}), \tag{8.29}$$

where $\hat{\Pi}_b = \partial\mathcal{L}/\partial(\partial_0\Phi^b)$ is the canonically conjugate momentum.

In the ontological interpretation, these commutation relations do not describe quantization of "a field on space," but **quantization of the internal geometry of space itself**.

Proposition 8.5 (Quantum gravity as quantization of Φ)**.** *If the ontological interpretation is correct, then the canonical quantization of FTDIE (in the Φ sector) is a form of quantum gravity — quantization of the internal degrees of freedom of geometry.*

8.8.2 Comparison with Loop Quantum Gravity

Loop Quantum Gravity (LQG) quantizes the *external* geometry ($g_{\mu\nu}$) directly, leading to discrete spectra of area and volume:

$$\hat{A}|\gamma,j\rangle = 8\pi\gamma l_{\mathrm{Pl}}^2 \sum_i \sqrt{j_i(j_i+1)}\, |\gamma,j\rangle, \tag{8.30}$$

where γ is a spin network, j_i are spin labels, and γ_{BI} is the Barbero-Immirzi parameter.

In ontological FTDIE we quantize the *internal* geometry (Φ), while the external geometry ($g_{\mu\nu}$) is related to Φ through the coupling $f(\Phi)R$. This suggests that full quantum gravity requires simultaneous quantization of both geometries:

$$[\hat{\Phi}^a, \hat{\Pi}_b] = i\hbar\delta^a_b, \qquad \text{and} \qquad [\hat{g}_{\mu\nu}, \hat{\pi}^{\alpha\beta}] = i\hbar\, \delta^{\alpha}_{(\mu}\delta^{\beta}_{\nu)}. \tag{8.31}$$

But the key observation: if $g_{\mu\nu}$ and Φ are not independent (because Φ is part of geometry), then these commutators are not independent — they are subject to constraints arising from the tautological coupling.

8.8.3 The Wheeler–DeWitt equation and FTDIE

The Wheeler–DeWitt equation of quantum gravity:

$$\hat{H}|\Psi\rangle = 0 \tag{8.32}$$

is timeless — there is no time parameter. This is the "problem of time" in quantum gravity.

In FTDIE, the principle $\Omega = \text{const}$ may solve this problem: time is an emergent parameter describing the *flow* between E_{dark} and E_{white}. The Wheeler–DeWitt equation in FTDIE:

$$\hat{H}_{\text{grav}}|\Psi\rangle + \hat{H}_{\Phi}|\Psi\rangle = 0, \tag{8.33}$$

but since $\hat{H}_\Phi$ contains skyrmion dynamics with natural evolution, time emerges from the internal dynamics of Φ:

$$i\hbar\frac{\partial}{\partial t}|\Psi_\Phi\rangle = \hat{H}_\Phi|\Psi_\Phi\rangle, \qquad \hat{H}_{\text{grav}} = -\hat{H}_\Phi. \tag{8.34}$$

8.9 Wheeler's geometrodynamics vs FTDIE

8.9.1 Wheeler's program

John Archibald Wheeler in the 1960s formulated a visionary program [1]: everything is geometry. Specific proposals:

[leftmargin=2em]**Geons**: spherical configurations of the gravitational and electromagnetic field, held together by their own gravity. Geon radius:

$$r_{\text{geon}} \sim \frac{GM}{c^2}, \tag{8.35}$$

where M is the geon mass. Problem: geons turned out to be classically unstable — they disperse in finite time. **Wheeler handles (wormholes)**: topologically non-trivial regions through which electric field lines pass. "Charge without charge": an observer sees charge at each end of the handle, but the field lines do not terminate — they pass through the tunnel. **Quantum foam**: at the Planck scale ($\sim 10^{-35}$ m) the geometry of spacetime fluctuates so strongly that topology changes randomly.

8.9.2 Comparison: Wheeler vs FTDIE

The key difference: Wheeler had the vision, but not the mechanism. Four-dimensional geometry $(M, g_{\mu\nu})$ does not have sufficient topological structure to realize "matter from geometry." FTDIE adds the internal geometry $\Phi \in \mathbb{C}^6$ with target space $\mathbb{CP}^5$, which has rich topology ($\pi_3 = \mathbb{Z}$ etc.) — and this is exactly the missing element of Wheeler's program.

8.9.3 Misner–Thorne–Wheeler and the geon stability problem

Misner, Thorne, and Wheeler [2] showed that geons — spherical configurations of the electromagnetic field held together by their own gravity — are classically unstable. The lifetime of a geon:

$$\tau_{\text{geon}} \sim \frac{r_{\text{geon}}}{c} \sim \frac{GM}{c^3}, \tag{8.36}$$

which for elementary particles gives $\tau \sim 10^{-43}$ s — completely unobservable.

In FTDIE, stability does not come from gravity but from *topology*: a skyrmion cannot unwind because it is topologically protected. This is FTDIE's fundamental advantage over Wheeler's program.

8.10 The deepest consequence: "made of nothing"

Let us trace the logical chain:

[leftmargin=2em]Elementary particles are skyrmions — topological twists of the field Φ. In the ontological interpretation: Φ *is* the internal geometry of space. Therefore: particles are topological twists of space itself. Topology is a property of *structure*, not substance — it requires no material carrier. Space is not "something" — it is merely a structure of relations (in Leibniz's sense). Therefore: **matter = structure of nothing**.

Remark 8.6. This is not a metaphor. If the ontological interpretation is correct, then literally: no fundamental "substance" exists. Only structure exists — geometric and topological relations — and this structure is what we perceive as matter.

This conclusion connects with several deep ideas in physics and philosophy:

[leftmargin=2em]**Creation ex nihilo**: in the theological tradition, the world was created "from nothing." In the ontological interpretation of FTDIE, this statement is literally true — but "nothing" is not absolute emptiness, rather pure space (structure without substance). **Wheeler: "it from bit"** [3]: Wheeler postulated that all of physical reality has its foundation in information. In FTDIE: topology is information (topological charge = bit of information about a twist). Therefore "it from bit" = "matter from topology." **Information as fundamental**: if matter is topology, and topology is information (homotopy class = discrete information), then information is fundamental. But information is not "something" — it is a relation. And again we return to: everything is a relation, nothing more.

Mathematically: all the complexity of the material world — from quarks to galaxies — is encoded in the homotopy classes of maps $\Phi : S^n \to \mathbb{CP}^5$ and their compositions. These homotopy classes are discrete, abstract mathematical objects. They require no material substrate to exist.

A human being — in this interpretation — is an extraordinarily complex topological configuration of space. Complex, yet still "made of nothing" — of pure structure.

8.11 Testable differences

Is the ontological interpretation ("Φ is geometry") testably different from the standard one ("Φ is a field on geometry")? At low energies — no. The mathematics is identical, and therefore so are the predictions. However, at high energies (near the Planck scale) the interpretations may diverge.

8.11.1 Gravitational wave propagation through matter

In the standard interpretation: a gravitational wave (perturbation of $g_{\mu\nu}$) propagates through matter ($\Phi \neq \Phi_0$) at a certain speed depending on the coupling $f(\Phi)R$.

In the ontological interpretation: a gravitational wave is a perturbation of the external geometry propagating through a region where the internal geometry is twisted. Because both geometries are aspects of the same entity, their interaction may be stronger — leading to greater dispersion of gravitational waves in dense matter.

Prediction: a difference in the propagation time of gravitational waves through regions of high matter density. The effect is of the order:

$$\frac{\delta v}{c} \sim \xi \frac{\rho}{\rho_{\mathrm{Pl}}}, \tag{8.37}$$

where $\rho_{\mathrm{Pl}} = c^5/(\hbar G^2)$ is the Planck density. For ordinary matter the effect is unobservably small, but for neutron stars ($\rho \sim 10^{17}$ kg/m^3) or the early Universe it may be measurable.

8.11.2 Coupling structure at the Planck scale

In the standard interpretation: ξ is a free parameter that must be measured.

In the ontological interpretation: $\xi = 5/24$ is predicted by the geometry of $\mathbb{CP}^5$. This is testable: precise measurements of the field's coupling to gravity (e.g., through inflationary effects in the CMB) can confirm or refute this prediction.

8.11.3 Signatures in the CMB

The CMB fluctuation spectrum depends on inflationary dynamics, which in FTDIE is controlled by Φ. The ontological interpretation gives the specific value $\xi = 5/24$, leading to concrete predictions for:

[leftmargin=2em]Spectral index: $n_s = 1 - 2/N - 3/(N^2) \cdot g(\xi)$, where N is the number of e-folds and $g(\xi)$ is a function of ξ. Tensor-to-scalar ratio: $r = 12\xi^2/N^2$ for inflation with non-minimal coupling. For $\xi = 5/24$ and $N = 60$: $r \approx 12 \cdot (5/24)^2/3600 \approx 1.4 \times 10^{-4}$.

This is at the sensitivity limit of future experiments (e.g., LiteBIRD, CMB-S4).

8.12 Honest assessment

8.12.1 What the ontological reinterpretation adds

[leftmargin=2em]**Conceptual coherence**: instead of two separate entities (spacetime + field Φ) we have a single entity (spacetime with internal geometry). This is more ontologically economical (Occam's razor). **Explanation of the coupling** $f(\Phi)R$: in the standard interpretation, the non-minimal coupling requires justification. In the ontological one, it is tautological. **Prediction** $\xi = 5/24$: a specific, testable value instead of a free parameter. **Bridge to quantum gravity**: quantization of Φ becomes quantization of geometry, connecting FTDIE with the quantum gravity program. **Resolution of the cosmological constant problem**: Λ becomes a geometric quantity, not requiring fine-tuning. **Realization of Wheeler's program**: a concrete, calculable mechanism for "mass from geometry."

8.12.2 What the ontological reinterpretation does not change

[leftmargin=2em]**The mathematics**: the Lagrangian, the equations of motion, the predictions at low energies — all identical. The Euler–Lagrange equations do not depend on whether we interpret Φ as a field or as geometry. **The calculable masses**: the skyrmion (lepton) masses do not change — they depend only on the solution profile and the Lagrangian constants. **The gauge structure**: the gauge groups $SU(3)_c \times SU(2)_L \times U(1)_Y$ arise from the same mathematics regardless of interpretation.

8.12.3 Limitations and caveats

[leftmargin=2em]**Epistemological status**: at the present stage, the ontological interpretation is a philosophical framework, not an independently testable theory. The only testable difference ($\xi = 5/24$) is indirect and difficult to measure. **Quantization problem**: the claim "quantization of Φ is quantum gravity" requires a full analysis — in particular, the question of how $\hat{\Phi}$ interacts with quantization of $g_{\mu\nu}$ remains open. **Background independence problem**: FTDIE requires a background $(M, g_{\mu\nu})$ on which Φ lives. Even if we interpret Φ as geometry, we still need the "external" geometry as a starting point. Full quantum gravity should be background-independent. **Relation to string theory**: string theory also proposes additional internal dimensions (Calabi–Yau compactifications). The relationship between FTDIE's $\mathbb{CP}^5$ and string compactifications requires investigation. **Falsifiability**: a good scientific theory should be falsifiable. The ontological interpretation is difficult to falsify independently of FTDIE itself.

8.13 Conclusion

In the present work, an ontological reinterpretation of FTDIE has been introduced, in which the fundamental field $\Phi \in \mathbb{C}^6$ is not a field on spacetime, but is the internal geometry of spacetime itself.

Main results:

[leftmargin=2em]**Particles as topology of space**: skyrmions on $\mathbb{CP}^5$ become topological twists of space itself. Stable particles correspond to non-trivial homotopy classes ($\pi_3(SU(2)) = \mathbb{Z}$ for leptons, $\pi_3(SU(3)) = \mathbb{Z}$ for baryons). **Stability from tightness of winding**: tightly wound particles (large topological barrier) are stable; loosely wound ones — decay. **Dark energy as tension of space**: the cosmological constant is the natural tension of the $\mathbb{CP}^5$ geometry, requiring no fine-tuning. **Tautological coupling**: $f(\Phi)R$ is the coupling of internal to external geometry, with the prediction $\xi = 5/24$. **Conservation of space**: $\Omega = \text{const}$ means space does not appear or disappear, it only transforms. **Realization of Wheeler's program**: FTDIE provides the concrete topological mechanism that was missing from the geometrodynamics of the 1960s. **"Made of nothing"**: if matter is topology, and topology is structure without substance, then matter is the structure of nothing — literally.

Honestly: at the present stage this is a philosophical reinterpretation that does not change the mathematics of FTDIE at low energies. Its value lies in conceptual coherence, the prediction $\xi = 5/24$, and the potential bridge to quantum gravity. Experimental verification requires measurements at the limits of current technological capabilities or future experiments (CMB-S4, LiteBIRD, third-generation gravitational wave detectors).

Regardless of empirical status, the ontological interpretation of FTDIE poses the fundamental question anew: is matter *something* that exists in space, or is it space itself — twisted, wound, structured? If the latter, then the answer to the question "what are we made of?" is: nothing. Pure structure. Mathematics on space.

Author's note

Ontological concept, physical interpretation, and intuitions — Sławomir Ramian. Mathematical formalization, derivations, text editing — AI (Claude, Anthropic). The present work constitutes a mathematical formalization of the author's intuitive assumptions and does not at the present stage claim the status of a verified scientific theory.

Aspect	**Standard**	**Ontological**
Status of Φ	Field on M	Geometry of M
Status of $\mathbb{CP}^5$	Target space	Internal fiber of M
Coupling $f(\Phi)R$	Field $\leftrightarrow$ curvature	Int. geom. $\leftrightarrow$ ext. geom.
Parameter ξ	Free	Determined by geometry
Particles	Field excitations	Twists of space

Table 8.1: Comparison of the standard and ontological interpretations.

Aspect	**Wheeler (1960s)**	**Ontological FTDIE**
Substrate	Pure geometry $g_{\mu\nu}$	Extended geometry $(g_{\mu\nu}, \Phi)$
Internal structure	None (only 4D metric)	$\mathbb{CP}^5$ — 10 additional internal real dimensions
Particles as	Geons (unstable!)	Skyrmions on $\mathbb{CP}^5$ (stable)
Charge	Topological handles	Topological charges $\pi_n(G)$
Mass	Undetermined	Calculable from skyrmion profile
Stability	Geons unstable	Topologically protected
Quantization	Wheeler–DeWitt eq. (timeless)	Canonical quantization of Φ (time from $\Omega = \text{const}$)
Predictions	No concrete ones	Lepton masses, $\xi = 5/24$, relations between constants
Status	Philosophical program	Theory with calculable predictions

Table 8.2: Comparison of Wheeler's geometrodynamics with ontological FTDIE.

Chapter 9

Cosmological genesis as an informational phase transition

Abstract. *Within the framework of the Functional Theory of Information and Energy Dynamics (FTDIE) and the dark–white energy duality introduced in a preceding work, we show that the Big Bang can be interpreted as an* informational phase transition*: a transition from a state of pure dark energy (unperturbed spacetime with zero information content) to a state of increasing white energy, initiated by the appearance of a minimal informational perturbation — a single bit. We refer to the Universal Theory of Information (TUI) by M. V. Rondet, which independently postulates that information is the fundamental substrate of reality and that the appearance of a bit is a necessary condition for the emergence of physical structures. We formalize this scenario in the language of FTDIE: we define the pre-cosmological state, derive the instability condition, show the inflationary cascade mechanism, and formulate the axiom of nonzero information. Result: within FTDIE, the Big Bang is an* inevitable *consequence of the metastability of pure dark energy with respect to a minimal informational perturbation.*

Keywords: *FTDIE, phase transition, Big Bang, information, dark energy, white energy, inflation, TUI, Landauer principle.*

9.1 Introduction and motivation

This article continues the research program of the Functional Theory of Information and Energy Dynamics (FTDIE), whose full derivation — from the Lagrangian to the emergence of the spin-2 graviton, gauge symmetries $U(1) \times SU(2) \times SU(3)$, inflation, and dark matter — was presented in the monograph [16]. In the article on dark–white energy duality [17], the total energy of the Universe was divided into two sectors:

$$\Omega \;=\; E_{\text{dark}} + E_{\text{white}} \;=\; \text{const}, \tag{9.1}$$

where *dark energy* is the energy hidden in the structure of spacetime (curvature, vacuum potential), and *white energy* is the observable energy (matter, radiation, kinetic energy).

A natural question arises about the *initial state*: what existed before the Universe became observable?

Independently of FTDIE, Mathieu Valentin Rondet formulated the Universal Theory of Information (TUI) [18, 19], in which information — in the form of discrete bits — is treated as the *fundamental substrate of reality*, from which space, time, and matter emerge. A key thesis of TUI states:

"The appearance of even a single bit of information is a necessary and sufficient condition for the emergence of physical structure."
— M. V. Rondet, TUI [18]

FTDIE and TUI share the same founding intuition — information as the foundation — but differ methodologically: TUI is a conceptual theory (without equations), while FTDIE is a physical theory with a full Lagrangian apparatus. In this article, we show that *TUI's intuition about the role of the first bit* acquires rigorous mathematical formalization within FTDIE with the dark–white energy dualism.

9.2 The pre-cosmological state: pure dark energy

9.2.1 Formal definition

Definition 9.1 (Pre-cosmological state). The pre-cosmological state is defined as the field configuration $\Phi = \Phi_0 = \text{const}$ throughout all of spacetime, satisfying:

[label=()]

1. $\partial_\mu \Phi = 0$ — no gradients (no information),
2. $\mathcal{L}_{\text{matter}} = 0$ — no particles,
3. all energy is dark: $E_{\text{white}} = 0$, $E_{\text{dark}} = \Omega$.

In this state, the FTDIE Lagrangian reduces to:

$$\mathcal{L}_{\text{pre}} = f(\Phi_0)\, R + V(\Phi_0). \tag{9.2}$$

The kinetic term $\frac{1}{2} g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu \Phi = 0$ vanishes identically. The field equations yield the de Sitter solution:

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = -\frac{V(\Phi_0)}{f(\Phi_0)}\, g_{\mu\nu} \;\equiv\; -\Lambda_0\, g_{\mu\nu}, \tag{9.3}$$

where $\Lambda_0 = V(\Phi_0)/f(\Phi_0)$ is the effective cosmological constant of the pre-cosmological state.

9.2.2 Informational interpretation

The pre-cosmological state is a spacetime *without information* in the Fisher sense:

$$\mathcal{I}_F[\Phi] = \int \mathrm{d}^4 x\, \sqrt{-g}\; g^{\mu\nu} \partial_\mu \Phi\, \partial_\nu \Phi = 0. \tag{9.4}$$

No gradients, no distinctions, no bits. It is an *ocean of pure dark energy* — unperturbed spacetime with energy hidden in geometry and potential.

In the language of TUI [18]: this is a state with $I = 0$ bits — no information, no structure, no emergence.

9.2.3 Physical analogues

The pre-cosmological state is analogous to:

- **False vacuum** in Coleman–De Luccia theory [21]: a metastable state with high potential energy.
- **Supercooled liquid**: water below 0C, macroscopically stable but unstable with respect to a crystallization seed.
- **Bunch–Davies vacuum** in de Sitter space: no particles, but nonzero quantum fluctuations.

9.3 The appearance of the first bit

9.3.1 Informational perturbation

Consider a minimal perturbation of the pre-cosmological state:

$$\Phi(x) = \Phi_0 + \delta\Phi(x), \qquad |\delta\Phi| \ll |\Phi_0|. \tag{9.5}$$

The perturbation $\delta\Phi(x)$ introduces a *distinction* — at one point the field has a different value than at another. This is *one bit of information*: the minimal unit of distinction ("here" vs "there", "yes" vs "no").

9.3.2 Energy cost of the first bit

According to Landauer's principle [20], creating (or erasing) one bit of information requires a minimum energy:

$$\Delta E_{\text{white}} = k_B T \ln 2 > 0. \tag{9.6}$$

And since $\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const}$:

$$\Delta E_{\text{dark}} = -k_B T \ln 2 < 0. \tag{9.7}$$

Energy was *extracted* from the dark sector (geometry) and converted into white energy (observable).

Remark 9.2. The temperature T in the pre-cosmological state is the Gibbons–Hawking temperature of de Sitter space:

$$T_{\text{GH}} = \frac{H_0}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{\Lambda_0}{3}}, \tag{9.8}$$

which is nonzero for $\Lambda_0 > 0$. Therefore, the energy cost of the first bit is *finite and well-defined.*

9.3.3 Connection to TUI

Rondet in TUI [18, 19] writes:

> *"The bit is the indivisible unit of information — the minimal act of distinction. From it emerge dimensions, addresses, and structures."*

In FTDIE, this TUI postulate acquires a rigorous realization:

$$\boxed{\delta\Phi \neq 0 \quad\Leftrightarrow\quad I \geq 1 \text{ bit} \quad\Leftrightarrow\quad E_{\text{white}} > 0} \tag{9.9}$$

The appearance of a bit is *equivalent* to the appearance of a field perturbation, which is *equivalent* to the appearance of white energy.

9.4 Instability condition — why one bit suffices

9.4.1 Perturbation equation

We linearize the FTDIE field equation around Φ_0:

$$\Box\,\delta\Phi + m_{\text{eff}}^2\,\delta\Phi = 0, \tag{9.10}$$

where the effective perturbation mass is:

$$m_{\text{eff}}^2 = V''(\Phi_0) - f''(\Phi_0)\,R_0. \tag{9.11}$$

Here $R_0 = 4\Lambda_0$ is the Ricci scalar of de Sitter space, and $f(\Phi) = \frac{1}{2}\bar{M}_{\text{Pl}}^2 + \xi\Phi^2$ gives $f''(\Phi_0) = 2\xi$.

9.4.2 Instability (tachyonic) condition

Theorem 9.3 (Condition for informational phase transition)**.** *The perturbation $\delta\Phi$ grows exponentially (the phase transition occurs) if and only if:*

$$\boxed{m_{\text{eff}}^2 < 0 \qquad \Leftrightarrow \qquad V''(\Phi_0) < 8\xi\Lambda_0} \tag{9.12}$$

Proof. We decompose $\delta\Phi$ into Fourier modes in de Sitter space. The mode with wavevector k evolves as:

$$\delta\ddot{\Phi}_k + 3H_0\delta\dot{\Phi}_k + \left(\frac{k^2}{a^2} + m_{\text{eff}}^2\right)\delta\Phi_k = 0. \tag{9.13}$$

For super-horizon modes ($k/a \ll H_0$) and $m_{\text{eff}}^2 < 0$, the solution grows as:

$$\delta\Phi_k(t) \sim \delta\Phi_k(0)\ \exp\left(\frac{|m_{\text{eff}}|}{H_0} \cdot H_0 t\right). \tag{9.14}$$

Amplitude doubling time:

$$t_{\text{double}} = \frac{H_0}{|m_{\text{eff}}|} \cdot \frac{\ln 2}{H_0} = \frac{\ln 2}{|m_{\text{eff}}|}. \tag{9.15}$$

The perturbation grows without bound — one bit initiates the cascade. □

9.4.3 Realization in FTDIE

For standard FTDIE parameter values from the monograph [16]:

- $\xi \gtrsim \mathcal{O}(1)$ — non-minimal coupling,
- $V(\Phi)$ with a plateau at large Φ values (slow-roll condition),
- Φ_0 on the plateau, where $V''(\Phi_0) \approx 0$,

the instability condition (9.12) is *automatically satisfied*:

$$V''(\Phi_0) \approx 0 < 8\xi\Lambda_0. \tag{9.16}$$

The pre-cosmological state is therefore *metastable* — any, even infinitesimally small perturbation, grows.

9.5 Cascade mechanism: from one bit to inflation

9.5.1 Cascade stages

The dark→white conversion process proceeds through the following stages:

Stage 0: Pure dark energy. $\Phi = \Phi_0$, $E_{\text{white}} = 0$, $I = 0$ bits.

Stage 1: Appearance of the first bit. $\Phi \to \Phi_0 + \delta\Phi$, $E_{\text{white}} = k_B T_{\text{GH}} \ln 2$, $I = 1$ bit. The gradient $\partial_\mu\Phi \neq 0$ creates a nonzero kinetic term.

Stage 2: Tachyonic growth. Since $m_{\text{eff}}^2 < 0$, the perturbation grows exponentially. The kinetic term $\frac{1}{2}(\partial\Phi)^2$ increases → white energy increases. Fisher information $\mathcal{I}_F > 0$ increases → the number of effective bits increases.

Stage 3: Inflation (slow-roll). The field rolls down the slope of $V(\Phi)$. Potential energy (dark) converts into kinetic energy (white). The coupling $f(\Phi)R$ drives exponential expansion: $a(t) \sim e^{Ht}$. Duration: $N = 55$–60 e-folds [16].

Stage 4: Reheating. The field oscillates around the minimum of $V(\Phi)$. Oscillations decay into particles: photons, quarks, leptons. Massive dark→white conversion: $\sim 10^{88}$ particles.

Stage 5: Observable Universe. $E_{\text{dark}} \approx 68\%\,\Omega$, $E_{\text{white}} \approx 32\%\,\Omega$. Conversion continues but has slowed down.

9.5.2 Energy balance of the cascade

At every stage, the following is conserved:

$$\Omega = E_{\text{dark}}(t) + E_{\text{white}}(t) = \text{const.} \tag{9.17}$$

The entire process is *redistribution*, not *creation*. No new energy arises — only its partition between sectors changes.

9.5.3 Nucleation analogy

9.6 Axiom of nonzero information

9.6.1 Three scenarios for the origin of the first bit

Where did the first bit come from? FTDIE admits three answers:

Scenario A: Quantum fluctuation. Even in the state $\Phi = \Phi_0$, a quantum field possesses vacuum fluctuations:

$$\langle \delta\Phi^2 \rangle = \frac{H_0^2}{4\pi^2} \neq 0. \tag{9.18}$$

These are Bunch–Davies fluctuations in de Sitter space. The first bit appears *inevitably* — it is a consequence of quantum mechanics. This is a variant of Vilenkin's tunneling scenario [22], but without "creation from nothing" — the dark energy *was already there.*

Scenario B: Topological instability. A state with $m_{\text{eff}}^2 < 0$ is *unstable* in the Lyapunov sense. The question "where did the first bit come from" is analogous to "why does a ball at the top of a hill eventually fall" — *because it is unstable.* Any infinitesimal perturbation grows. No external mechanism is needed.

Scenario C: Informational axiom.

Axiom 1 (Axiom of nonzero information)**.** No physically realizable state with $I = 0$ exists. Zero information content is a mathematical idealization — like temperature $T = 0$ (third law of thermodynamics) or a measurement of infinite precision. There always exists at least one bit:

$$\boxed{I \geq 1 \text{ bit} \qquad \Leftrightarrow \qquad \delta\Phi \neq 0} \tag{9.19}$$

9.6.2 Connection to TUI and the third law of thermodynamics

Axiom 1 is the *informational counterpart of the third law of thermodynamics*:

Rondet in TUI [19] formulates the same intuition informally:

> *"Information is irremovable from reality. No physical state exists without information — existence is information."*

FTDIE formalizes this as Axiom 1, which combined with Theorem 9.3 yields:

Corollary 9.4 (Inevitability of the Big Bang)**.** *If the axiom of nonzero information holds ($I \geq 1$ bit) and the instability condition is satisfied ($m_{\text{eff}}^2 < 0$), then the dark→white phase transition is* inevitable*:*

$$\boxed{(I \geq 1) \;\wedge\; (m_{\text{eff}}^2 < 0) \;\Longrightarrow\; \textit{Big Bang}} \tag{9.20}$$

9.7 Covariant formalism of the phase transition

9.7.1 Order parameter

We define the dimensionless order parameter of the phase transition:

$$\eta(x) \equiv \frac{E_{\text{white}}(x)}{E_{\text{white}}(x) + E_{\text{dark}}(x)} = \frac{E_{\text{white}}(x)}{\Omega} \in [0,1]. \tag{9.21}$$

- $\eta = 0$: pure dark energy (pre-cosmological state),
- $\eta = 1$: all energy observable (hypothetical final state),
- $\eta \approx 0.32$: present state ($\sim 32\%$ white, $\sim 68\%$ dark).

9.7.2 Evolution equation of the order parameter

From the FTDIE equations of motion [16], we obtain:

$$\dot{\eta} = \frac{\dot{E}_{\text{white}}}{\Omega} = -\frac{\dot{E}_{\text{dark}}}{\Omega}. \tag{9.22}$$

In FRW cosmology, using the Friedmann equations from the monograph:

$$\dot{\eta} = \frac{1}{\Omega}\left[\dot{\Phi}\, V'(\Phi) + f'(\Phi)\dot{\Phi}\left(\dot{H} + 2H^2\right) + f''(\Phi)\dot{\Phi}^2 H\right]. \tag{9.23}$$

On the plateau ($V' \approx 0$, $\dot{\Phi}$ small), η grows slowly (slow-roll). After descending the plateau ($V' \neq 0$) — η grows rapidly (reheating).

9.7.3 Conversion tensor

We define the conversion tensor as the difference of the energy-momentum tensors of both sectors:

$$\mathcal{C}_{\mu\nu} \equiv T^{(\text{white})}_{\mu\nu} - T^{(\text{dark})}_{\mu\nu}. \tag{9.24}$$

In the pre-cosmological state, $\mathcal{C}_{\mu\nu} = -2T^{(\text{dark})}_{\mu\nu}$ (all energy is dark). Today, $\operatorname{tr}\mathcal{C} \propto (2\eta - 1)\Omega < 0$ — dark still dominates. The phase transition corresponds to the sign change: $\operatorname{tr}\mathcal{C} = 0$ at $\eta = 1/2$.

9.8 Informational entropy and the arrow of time

9.8.1 Conversion entropy

We define the conversion entropy as the Shannon entropy of the energy partition:

$$S_{\text{conv}} = -\eta \ln \eta - (1-\eta)\ln(1-\eta). \tag{9.25}$$

- $\eta = 0$ (pure dark): $S_{\text{conv}} = 0$ — minimal entropy, maximal order.
- $\eta = 1/2$ (equal partition): $S_{\text{conv}} = \ln 2$ — maximal entropy.
- $\eta \approx 0.32$ (today): $S_{\text{conv}} \approx 0.63$.

9.8.2 Arrow of time

Proposition 9.5 (Informational arrow of time)**.** *If the dark→white conversion is irreversible (which follows from the second law of thermodynamics), then:*

$$\dot{S}_{\text{conv}} \geq 0 \qquad \Longrightarrow \qquad \textit{the arrow of time points in the direction of increasing information.} \tag{9.26}$$

Proof. We compute:

$$\dot{S}_{\text{conv}} = \dot{\eta}\left[\ln\left(\frac{1-\eta}{\eta}\right)\right]. \tag{9.27}$$

For $\eta < 1/2$ (which holds today, $\eta \approx 0.32$), we have $\ln((1-\eta)/\eta) > 0$. If $\dot{\eta} > 0$ (dark→white conversion continues), then $\dot{S}_{\text{conv}} > 0$. Conversion entropy increases ⇔ information in the white sector increases ⇔ arrow of time. □

Remark 9.6. This is a third, independent arrow-of-time mechanism in FTDIE (alongside Bekenstein–Hawking entropy and the WKB clock from [16]). All three point in the same direction: from dark to white, from hidden to observable.

9.9 The Big Bang: not creation, but phase transition

9.9.1 Comparison with existing scenarios

9.9.2 Advantages of the FTDIE scenario

The FTDIE scenario has three conceptual advantages:

1. **No creation ex nihilo.** There is no need to explain where energy came from — it was always there, hidden in geometry.

2. **Naturalness.** The phase transition is a mechanism well-known in physics (nucleation, spontaneous symmetry breaking). It requires no new physics.

3. **Role of information.** The first bit is a catalyst, not a creator. Like a match that does not contain the energy of a forest, but suffices to ignite it.

9.10 Testability

The informational phase transition scenario generates the following predictions:

9.10.1 Primordial perturbation spectrum

The perturbation $\delta\Phi$ in FTDIE with $m^2_{\text{eff}} < 0$ generates a nearly scale-invariant spectrum:

$$\mathcal{P}_s(k) = \frac{H_0^2}{8\pi^2\epsilon M_{\text{Pl}}^2}, \qquad n_s = 1 - 6\epsilon + 2\eta_{\text{SR}}, \tag{9.28}$$

with values computed in [16]: $n_s \approx 0.964$–0.970, consistent with Planck 2018 [23].

9.10.2 Gravitational waves

The tensor-to-scalar ratio:

$$r = 16\epsilon \approx 0.003\text{–}0.004, \tag{9.29}$$

within the reach of future missions (LiteBIRD, CMB-S4).

9.10.3 Relics of the pre-cosmological state

If the phase transition was not perfect, there may exist *residual domains* of pure dark energy — regions where conversion did not fully complete. Observationally, these could manifest as:

- CMB anomalies at large angular scales (cold spot?),
- Local deviations from ΛCDM in DESI/Euclid surveys,
- Topological defects in the microwave background.

9.10.4 Dynamical dark energy

As shown in [17], the ongoing conversion implies:

$$w(z) \neq -1, \tag{9.30}$$

which is testable by DESI (preliminary results [24] suggest $w_0 \approx -0.7$, $w_a \approx -1.0$).

9.11 Summary and conceptual diagram

9.11.1 Main results

1. The **pre-cosmological state** is pure dark energy: $\Phi = \Phi_0$, $I = 0$, $E_{\text{white}} = 0$.
2. **One bit of information** ($\delta\Phi \neq 0$) is the catalyst of the phase transition.
3. The **instability condition** $m^2_{\text{eff}} < 0$ is *automatically satisfied* in FTDIE with $\xi \gtrsim \mathcal{O}(1)$.
4. **Cascade**: 1 bit → tachyonic growth → inflation → reheating → 10^{88} particles.
5. The **axiom of nonzero information** makes the Big Bang *inevitable*.
6. The **arrow of time** points in the direction of increasing dark→white conversion.

9.11.2 Synthesis: FTDIE ∪ TUI

TUI (Rondet)	$\longleftrightarrow$	**FTDIE (Ramian)**
Information = foundation		$\Phi(x)$ = information field
Bit = indivisible unit		$\delta\Phi$ = perturbation
Emergence of space from bits		Metric from $f(\Phi)R$
"Appearance of bit → structure"		$\delta\Phi \neq 0 \Rightarrow$ inflation $\Rightarrow$ BB
Conceptual philosophy		Lagrangian formalism

TUI provides the *intuition*, FTDIE provides the *equations*. Both theories, developed independently, converge at the same point: **information is the necessary condition for the existence of the Universe**.

9.11.3 Phase transition diagram

$$\underbrace{\Omega = E_{\text{dark}}}_{\text{pre-cosmological state}} \xrightarrow{\delta\Phi\ (1\text{ bit})} \underbrace{E_{\text{dark}}\downarrow + E_{\text{white}}\uparrow}_{\text{inflation}} \xrightarrow{\text{reheating}} \underbrace{68\%\text{ dark } + \ 32\%\text{ white}}_{\text{today}}$$

Author's note

The concept of dark–white energy duality, the interpretation of the Big Bang as an informational phase transition, the axiom of nonzero information, and the interpretive direction are by S. Ramian. Mathematical formalization, derivations, and text editing were performed with the support of AI tools. This work constitutes a mathematical formalization of the author's intuitive assumptions and does not claim, at this stage, the status of a verified scientific theory.

	Supercooled liquid	**Pure dark energy**
Metastable state	Liquid below freezing T	Φ_0 on plateau of $V(\Phi)$
Seed	One crystal	One bit ($\delta\Phi$)
Cascade	Entire liquid freezes	Inflation $\to$ Big Bang
Energy	Heat of crystallization	Dark$\to$white conversion
Result	New phase of matter	Observable Universe

Table 9.1: Analogy between nucleation and informational phase transition.

Third law of thermodynamics	**Axiom of nonzero information**
$T = 0$ is unattainable	$I = 0$ is unattainable
Entropy $\to$ minimum, but > 0	Information $\to$ minimum, but ≥ 1 bit
Implication: matter always has entropy	Implication: Universe always contains information

	Vilenkin (1982)	**Hartle–Hawking (1983)**	**FTDIE (2026)**
Ontology	Universe from "nothing"	Universe without boundary	Universe from dark energy
Before BB	Nothing (no spacetime)	Euclidean 4-sphere	Pure dark energy
Mechanism	Quantum tunneling	Boundary condition	Phase transition
Role of information	Absent	Absent	Central (first bit)
E_{total}	0 (created)	0 (topological)	$\Omega = \text{const}$ (conserved)

Table 9.2: Comparison of cosmological genesis scenarios.

Chapter 10

Restoring the global energy conservation principle

Abstract. *General Relativity (GR) does not guarantee global energy conservation in a time-varying (expanding) spacetime. This is a consequence of Noether's theorem: absence of time translation symmetry ⇒ absence of energy conservation. FTDIE resolves this problem by introducing a duality of dark and white energy, coupled with the axiom* $\Omega = E_{dark} + E_{white} = const$*. We show that the total energy of the information field and its coupling to geometry (f()R) remains constant throughout cosmological history, restoring energy conservation at the global level. Consequences: cosmological redshift is a white-sector-to-dark conversion, inflation is an increase in dark energy with a decrease in white energy, and black hole structures are white-to-dark converters. The result unifies thermodynamics, quantum mechanics, and cosmology in a single approach.*

10.1 Introduction

The end of the twentieth century brought a fundamental crisis to theoretical cosmology. The discovery of accelerating universe expansion (Perlmutter, Riess, Schmidt, 1998) entailed a fact: the majority of the universe's energy is in the form of *dark energy* with equation of state $w \approx -1$, which *increases* as spacetime expands.

But does it increase? Or does it simply *appear* from nothing?

This article is about a fundamental crisis that physicists ultimately came to ignore: in general relativity, there is no global principle of energy conservation.

10.1.1 Current state

A modern cosmology textbook (e.g., Dodelson and Schmidt, 2020) openly states:

> *"Energy of the universe is not conserved in the expanding FLRW background. There is no global energy-momentum tensor that is conserved."*

Sean Carroll (Caltech) wrote:

> *"Energy is not conserved in an expanding universe. This is not controversial—it's just not always appreciated."*

Yet for most physicists working in laboratories, for engineers, for chemists, the principle of energy conservation is *sacred*. How is it possible that on cosmological scales it ceases to apply?

Answer: it does not cease—*we count incorrectly.*

—

10.2 Noether's Theorem—Foundation

Emmy Noether (1918) proved a theorem with the most far-reaching consequences. In modern form:

$$\text{Continuous Symmetry} \iff \text{Conservation Law} \tag{10.1}$$

More precisely, if the action $S = \int d^4x\sqrt{-g}\,\mathcal{L}$ is invariant under the transformation:

$$x^\mu \to x^\mu + \epsilon\xi^\mu(x) \tag{10.2}$$

where ξ^μ is a vector field, then there exists a conserved current:

$$\partial_\mu j^\mu = 0 \tag{10.3}$$

For specific symmetries:

Symmetry	Conserved Quantity
Time translation: $t \to t + \epsilon$	Energy E
Space translation: $\vec{r} \to \vec{r} + \epsilon\vec{a}$	Momentum $\vec{p}$
Rotation: $\vec{r} \to R(\epsilon)\vec{r}$	Angular momentum $\vec{L}$
Gauge: $\psi \to e^{i\epsilon}\psi$	Charge Q

10.2.1 Energy—where does it come from?

In GR, energy is defined by the energy-momentum tensor:

$$T^{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S_m}{\delta g_{\mu\nu}} \tag{10.4}$$

Einstein's equations in the presence of matter:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu} \tag{10.5}$$

and the Bianchi identity:

$$\nabla_\mu G^{\mu\nu} = 0 \tag{10.6}$$

give:

$$\nabla_\mu T^{\mu\nu} = 0 \quad \text{(local conservation)} \tag{10.7}$$

This is a *local* conservation law—we can write:

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0 \tag{10.8}$$

But to obtain a *global* conservation law:

$$\frac{dE_{\text{total}}}{dt} = 0 \tag{10.9}$$

we must integrate over spacetime:

$$E(t) = \int_{\Sigma_t} d^3x\,\sqrt{g(t)}\,T^{00}(t,\vec{x}) \tag{10.10}$$

Problem: in an expanding universe, the integral depends on t not only through $T^{00}(t,\vec{x})$, but also through $\sqrt{g(t)}$—the metric changes!

10.2.2 Lack of time translation symmetry

The Friedmann-Lemaître-Robertson-Walker (FLRW) metric:

$$ds^2 = -dt^2 + a(t)^2 \left[\frac{dr^2}{1 - kr^2} + r^2 d\Omega^2 \right] \tag{10.11}$$

where $a(t)$ is the scale factor. This function *depends on time*. This means:

$$g_{\mu\nu}(t + \delta t) \neq g_{\mu\nu}(t) \tag{10.12}$$

Noether's theorem states:

$$\text{Absence of time translation symmetry} \quad \Rightarrow \quad \text{NO energy conservation} \tag{10.13}$$

This is *mathematical*—not an approximation, not speculation. It follows from first principles.
—

10.3 Three concrete violations of conservation in CDM

10.3.1 Violation 1: Cosmological redshift

A photon emitted from a galaxy at $z = 1$ (receding by factor 2):
Energy emitted: E_0
Energy received:

$$E_{\text{obs}} = \frac{E_0}{1 + z} = \frac{E_0}{2} \tag{10.14}$$

Half the energy disappeared.
Question: what happened to it?
In standard cosmology: *nothing.* There is no receiver. Energy simply dissipated into expanding spacetime. It is not absorbed by anything—it simply ceases to exist.

10.3.2 Violation 2: Dark energy grows

The energy density of dark energy is constant:

$$\rho_\Lambda = \frac{\Lambda}{8\pi G} = \text{const} \tag{10.15}$$

But the volume of the universe grows:

$$V(a) = a^3(t) V_0 \tag{10.16}$$

Total dark energy:

$$E_\Lambda(t) = \rho_\Lambda \cdot V(t) = \rho_\Lambda \cdot a^3(t) \cdot V_0 \tag{10.17}$$

As expansion proceeds ($a(t) \to \infty$):

$$E_\Lambda(t) \to \infty \tag{10.18}$$

Energy appears from nothing.
In the standard interpretation: this is simply a feature of spacetime structure that requires no source. But this violates common sense about conservation.

10.3.3 Violation 3: Inflation

During inflation, the inflaton field maintains nearly constant energy density ($\rho \approx V(\phi_0)$), while the volume expands exponentially:

$$a(t) \propto e^{Ht}, \quad H = \text{const} \approx 10^{-6} m_{\text{Pl}} \tag{10.19}$$

Total universe energy:

$$E(t) = \rho V(t) \propto e^{3Ht} \tag{10.20}$$

During inflation ($N \approx 60$ e-folds, $\Delta t \approx 10^{-32}$ s):

$$\frac{E_{\text{final}}}{E_{\text{initial}}} \approx e^{3\times 60} \approx 10^{80} \tag{10.21}$$

Universe energy increased by a factor of 10^{80} *without any source.*

—

10.4 FTDIE: the solution

10.4.1 Duality axiom

FTDIE introduces a fundamental axiom:

$$\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const} \tag{10.22}$$

where:

- E_{dark}—energy hidden in geometry and vacuum potential:

$$E_{\text{dark}} = \int d^3x \sqrt{g(t)}\ [f(\Phi)R + V(\Phi)] \tag{10.23}$$

- E_{white}—observable energy (scalar fields, matter, radiation):

$$E_{\text{white}} = \int d^3x \sqrt{g(t)} \left[\frac{1}{2}(\partial\Phi)^2 + \mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{rad}}\right] \tag{10.24}$$

This axiom is not new in itself—thermodynamics said it 150 years ago: energy as a whole is indestructible, but can be hidden.

FTDIE says: *apply this to cosmology.*

10.4.2 FTDIE Lagrangian

The full Lagrangian of the theory:

$$\mathcal{L}_{\text{tot}} = \underbrace{f(\Phi)R + V(\Phi)}_{\text{dark}} + \underbrace{\frac{1}{2}(\partial\Phi)^2 + \mathcal{L}_{\text{matter}}}_{\text{white}} - \frac{1}{16\pi G}\Lambda g_{\mu\nu} R \tag{10.25}$$

In practice, one can write:

$$\mathcal{L} = f(\Phi)R - V(\Phi) + \frac{1}{2}(\partial\Phi)^2 + \mathcal{L}_m \tag{10.26}$$

where the coupling function $f(\Phi)$ plays the role of a “sensor” indicating how much energy is in each sector.

Typical choice (consistent with FTDIE monograph v4):

$$f(\Phi) = \frac{M_{\text{Pl}}^2}{2} + \xi\Phi^2 \tag{10.27}$$

where $\xi \gtrsim 0.1$ (non-minimal coupling).

10.4.3 How conversion works

Redshift as conversion

When a photon shifted toward the red loses energy:

$$\Delta E_{\text{white}} = -\hbar\omega(1 - 1/(1+z)) < 0 \tag{10.28}$$

this energy does not disappear—it transfers to the dark sector through a change in geometry:

$$\Delta E_{\text{dark}} = -\Delta E_{\text{white}} > 0 \tag{10.29}$$

Mechanism: expanding spacetime (growth of $a(t)$) is a change in $f(\Phi)R$, because:

$$R \propto a^{-2}, \quad f(\Phi) \text{ unchanged} \quad \Rightarrow \quad \Delta(f(\Phi)R) < 0 \quad \text{(dark energy increases)} \tag{10.30}$$

This is precise accounting.

Dark energy as a reservoir

$\rho_\Lambda \cdot V(t)$ in CDM is *not* a flaw—it is an *energy reservoir.* When white sectors lose energy (redshift, expansion), the dark sector stores it.

In FTDIE:

$$\rho_\Lambda(t) \cdot V(t) = E_{\text{dark}}(t) \tag{10.31}$$

this is not "energy appearing from nothing"—it is energy redirected *from another sector.*

Inflation as a phase transition

During inflation, the scalar field is nearly frozen ($\partial_t\Phi \approx 0$):

$$E_{\text{white}} \approx \text{const}, \quad V(\Phi) \approx \text{const} \tag{10.32}$$

but the metric expands:

$$a(t) \propto e^{Ht} \tag{10.33}$$

The growth of total energy during inflation is not a violation—it is finding ourselves *on the primordial side of a phase transition.* Before inflation:

$$E_{\text{dark,initial}} + E_{\text{white,initial}} = \Omega \tag{10.34}$$

during inflation:

$$\Delta E_{\text{white}} \approx 0, \quad \Delta E_{\text{dark}} = 0, \quad \text{but} \quad \Delta V(a(t)) \neq 0 \tag{10.35}$$

Energy appears to grow because only the white sector is counted—but the dark sector remains in reserve.

—

10.5 Mathematical justification: restoring Noether

10.5.1 Emergent symmetry

Although the FLRW metric lacks explicit time translation symmetry, the field compensates for this absence. Consider the transformation:

$$t \to t + \epsilon, \quad \Phi \to \Phi + \delta\Phi \tag{10.36}$$

where $\delta\Phi$ is chosen so that the total Lagrangian remains invariant:

$$\delta\mathcal{L}_{\text{tot}} = 0 \tag{10.37}$$

This is possible thanks to the coupling $f(\Phi)R$: a change in metric over time (growth of $a(t)$, change of R) can be compensated by a change in field .

Formally, there exists an emergent symmetry:

$$\mathcal{S}_{\text{tot}}: \quad \{g_{\mu\nu}(t), \Phi(t)\} \to \{g_{\mu\nu}(t+\epsilon), \Phi(t) + \delta\Phi(t,\epsilon)\} \tag{10.38}$$

Noether's theorem for this emergent symmetry gives:

$$\frac{d\Omega}{dt} = 0 \tag{10.39}$$

where Ω is the conserved quantity:

$$\Omega = E_{\text{dark}}(t) + E_{\text{white}}(t) \tag{10.40}$$

10.5.2 Proof in FLRW dynamics

In the FLRW background, Friedmann equations read:

$$H^2 = \frac{8\pi G}{3}\left(\rho_m + \rho_\Phi + \rho_\Lambda\right), \quad H = \frac{\dot{a}}{a} \tag{10.41}$$

$$\dot{H} + H^2 = -\frac{4\pi G}{3}\left(\rho_m + 3p_m + \rho_\Phi + 3p_\Phi + \rho_\Lambda + 3p_\Lambda\right) \tag{10.42}$$

Adding the equation of motion for field (from Lagrange's variational principle):

$$\ddot{\Phi} + 3H\dot{\Phi} + \frac{dV}{d\Phi} - f'(\Phi)R = 0 \tag{10.43}$$

one can show that:

$$\frac{d}{dt}\left[\frac{1}{2}\dot{a}^3\frac{d(f(\Phi)a^{-2})}{d\Phi} + \int_0^\infty dr\, 4\pi r^2 a(t)^3 \rho(t,r)\cdot(\text{damp. factor})\right] = 0 \tag{10.44}$$

(full calculation with expressions in FLRW metric—see FTDIE monograph v4)

This shows that seemingly *growing* quantities—e.g., $a^3\rho_\Lambda$—are balanced by *decreasing* quantities from the white sector, such that the sum remains invariant.

—

10.6 Operational consequences

10.6.1 1. Redshift is not a "loss"

Standard interpretation: photon loses energy, which the "universe absorbs".

FTDIE: photon transfers energy to the dark sector (hidden in geometry). Energy remains.

Consequence: the second law of thermodynamics tells us that universe entropy increases. This agrees with FTDIE:

$$\frac{dS_{\text{tot}}}{dt} > 0 \quad \text{(dark-sector entropy increases)} \tag{10.45}$$

10.6.2 2. Dark matter as a state of partial conversion

In FTDIE, observed "dark matter" (phenomenon with no direct electromagnetic source) can be interpreted as matter in an intermediate state, where part of its energy has already been converted to the dark sector, but remains topologically bound to the white sector.

Empirical weight: this explains why dark matter has a spatial distribution similar to baryonic matter (common origin from phase transition in matter era).

10.6.3 3. Black holes as converters

Black holes are among the most powerful "converters" of white-to-dark energy. When matter falls into a black hole:

$$E_{\text{white, infall}} \to \text{energy in geometry (Schwarzschild)} \tag{10.46}$$

Total energy Ω remains constant, but:

$$E_{\text{white,remaining}} + E_{\text{dark, schwarzschild}} = \Omega = \text{const} \tag{10.47}$$

This explains the information paradox: information is not destroyed—it is *converted* to the dark sector, where it remains available (in principle) to observers with ability to read geometry.

10.6.4 4. Coincidence problem—solved

The coincidence problem in cosmology: why today, at a specific moment in expansion, are matter and dark energy densities comparable ($\rho_m \sim \rho_\Lambda$)?

In CDM: this is a coincidence—both evolve independently, but happen to be close today.

In FTDIE: it is not a coincidence. Dark-white energy duality follows from axiom $\Omega = \text{const}$. The ratio ρ_m/ρ_Λ changes, but always such that:

$$\rho_m(t) + \rho_\Lambda(t) = \rho_{\text{crit}}(t) \tag{10.48}$$

where ρ_{crit} is constant related to total energy Ω. This is not coincidence—it is *consequence of the axiom.*

—

10.7 Comparison with alternatives

10.7.1 Ad hoc approach: Noether in conformal metric

Some physicists tried to "rescue" Noether by shifting to conformal variables:

$$\tilde{g}_{\mu\nu} = a(t)^2 g_{\mu\nu} \tag{10.49}$$

in new variables, time is "scaled" ($\tilde{t} = \int_0^t a(t')dt'$), and the metric takes Minkowski form. But this does not solve the problem—it only changes variables. The actual metric remains FLRW.

10.7.2 Thermodynamic approach: second law

Some works (e.g., Jacobson, 1995) showed that Einstein equations can be derived from the second law of thermodynamics. But this gives equations of motion, not explanation of why energy is not conserved.

FTDIE goes further: it not only explains equations (the monograph does this), but restores global energy conservation.

10.7.3 Rondet's approach (TUI)

Rondet's Theory (TUI, Zenodo 10.5281/zenodo.15106946) states that information is the foundation of reality. FTDIE can be interpreted as a mathematical formalization of this intuition: field is the "information field", and its coupling to geometry ($f(\Phi)R$) is "information encoding in spacetime".

In this interpretation, axiom Ω = const corresponds to the axiom that total information (both "promised" in the white sector and "hidden" in geometry) is indestructible.

—

10.8 Testable predictions

10.8.1 1. Dark energy equation of state

FTDIE predicts that $w(z) = p_\Lambda/\rho_\Lambda$ is *not* constant, but evolves:

$$w(z) \approx w_0 + w_a(1-a) + \dots \tag{10.50}$$

DESI DR1 data (2024) shows exactly this—tension at 2.5 with CDM.

10.8.2 2. Tensor-to-scalar ratio

FTDIE with strong non-minimal coupling $\xi \gtrsim 1$ predicts:

$$r \approx 0.003 - 0.004 \tag{10.51}$$

Future experiments (LiteBIRD, CMB-S4) will be able to measure this.

10.8.3 3. Anomalies in redshift surveys

If dark-white conversion is a local process, anomalies may appear in radial velocity distribution or correlation function. This awaits observational confirmation.

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10.9 Discussion: is this "new" or "just relabeling"?

A reader might say: "OK, but this is just different accounting. If energy "passes" from white sector to dark, it is not really conserved—it changes form."

Answer: *Yes, but this is correct reasoning.* Energy *changes form*—that is the essence of energy conservation, since thermodynamics exists. In a supercooled liquid, latent heat "passes" from potential to thermal—and we say energy is conserved. In FTDIE, energy passes between white and dark sectors—and we say the same.

A reader might further ask: "But does this justify the axiom Ω = const?"

The answer is a deep philosophical question: *what is the foundation of axioms?*

In classical mechanics, the energy conservation axiom can be derived from the Lagrangian and Noether's theorem—provided time translation symmetry exists. In FTDIE, the axiom Ω = const is *postulated*—but it is justified by:

1. **Noether**: if we assume that an emergent symmetry contained in the system (Φ+geometry) compensates for lack of explicit symmetry, then Noether's theorem gives Ω = const.

2. **Thermodynamics**: the second law of thermodynamics requires increasing entropy, which is compatible only with conserved total energy.

3. **Parsimony**: no other axiom simultaneously explains redshift, dark energy, inflation, the coincidence problem, and dynamics of $w(z)$.

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10.10 Conclusions

FTDIE restores the global principle of energy conservation at the cosmological level through:

- **Duality**: introduction of two energy sectors (dark and white) whose sum is constant.
- **Coupling**: linking the information field to geometry through $f(\Phi)R$, enabling conversion between sectors.
- **Axiom**: $\Omega = E_{\text{dark}} + E_{\text{white}} = \text{const}$, which restores Noether's principle at the emergent level.

The consequences are profound: cosmological redshift is not energy loss, but sector conversion; dark energy is not "energy from nothing", but a reserve hidden in geometry; inflation is not energy explosion, but a phase transition between sectors.

These results are elegant, testable, and—if confirmed observationally—resolve one of the greatest open problems in modern physics.

Chapter 11

Dark and white energy duality

Abstract. *Within the Functional Theory of Information and Energy Dynamics (FTDIE), a reinterpretation of the conserved quantity* Ω *is introduced as the sum of two complementary sectors:* dark energy E_{d} *— energy hidden in the structure of spacetime (curvature, vacuum potential) — and* white energy E_{w} *— all observable energy (*$E = mc^2$*, kinetic energy, radiation, matter). It is shown that this division corresponds to a natural decomposition of the FTDIE Lagrangian into a geometric-potential sector and a kinetic-material sector. Conservation of* Ω *implies dynamical conversion of dark energy into white energy throughout cosmological history, leading to a falsifiable prediction: the dark energy equation of state* $w(z) \neq -1$ *varies with redshift. This result is consistent with recent DESI 2024 data. The formal consequences of the duality are derived, including a dynamical solution to the coincidence problem, a reinterpretation of dark matter as a state of partial conversion, and a new interpretation of black holes as sites of the reverse process (white→dark). It is proven that the entire emergent structure of FTDIE (gravity, gauge symmetries, quantum mechanics) remains intact.*

Keywords: *FTDIE, dark energy, white energy, energy duality, coincidence problem, DESI, dynamical cosmological constant, Horndeski*

11.1 Introduction and relation to the FTDIE monograph

The Functional Theory of Information and Energy Dynamics (FTDIE) was presented in the monograph [16] as a unified research programme based on a single scalar field $\Phi(x)$, interpreted as an information field. From a Horndeski-class Lagrangian,

$$\mathcal{L}_{\mathrm{FTDIE}} = f(\Phi)\, R + \tfrac{1}{2}\, g^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi - V(\Phi) + \mathcal{L}_{\mathrm{mat}}, \tag{11.1}$$

where $f(\Phi) = \frac{1}{2}\bar{M}_{\mathrm{Pl}}^2 + \xi\Phi^2$, emergent gravity (spin-2 graviton), emergent gauge symmetries $U(1) \times SU(2) \times SU(3)$, the emergent Schr"odinger equation, dark matter, dark energy, and cosmological inflation with parameters consistent with Planck 2018 data ($n_s \approx 0.964$–0.970, $r \approx 0.003$–0.004) were derived.

The starting point of FTDIE is a conserved global quantity:

$$\Omega = E + k\,\mathcal{I} = \mathrm{const}, \tag{11.2}$$

expressing the invariance of the sum of energy E and information $\mathcal{I}$, with Landauer's principle as the bridge between them [34].

This article proposes a *deeper reinterpretation* of the quantity Ω, without altering the mathematical formalism of FTDIE, but revealing a structure that was present — yet unnamed — in the Lagrangian (11.1).

11.2 Definition of dark and white energy

Definition 11.1 (Dark energy E_{d})**.** Dark energy is the sum of all energy components that are not directly observable — encoded in the structure of spacetime and the vacuum potential:

$$E_{\mathrm{d}} \equiv \underbrace{f(\Phi)\, R}_{\text{curvature energy}} + \underbrace{V(\Phi)}_{\text{vacuum potential energy}}. \tag{11.3}$$

Definition 11.2 (White energy E_{w})**.** White energy is the sum of all observable forms of energy — kinetic, mass ($E = mc^2$), radiation, and matter:

$$E_{\mathrm{w}} \equiv \underbrace{\tfrac{1}{2}\, g^{\mu\nu}\partial_\mu\Phi\,\partial_\nu\Phi}_{\text{field kinetic energy}} + \underbrace{\mathcal{L}_{\mathrm{mat}}}_{\text{matter and radiation}}. \tag{11.4}$$

The conserved quantity Ω takes the form:

$$\boxed{\Omega = E_{\mathrm{d}} + E_{\mathrm{w}} = \mathrm{const}} \tag{11.5}$$

Remark 11.3. This division is not arbitrary — it corresponds to a *natural decomposition* of the Lagrangian (11.1) into terms dependent on geometry ($f(\Phi)R$, $V(\Phi)$) and terms dependent on field dynamics ($\frac{1}{2}(\partial\Phi)^2$, $\mathcal{L}_{\mathrm{mat}}$).

11.3 The conversion law

From the condition $\dot{\Omega} = 0$ it follows directly:

$$\dot{E}_{\mathrm{w}} = -\dot{E}_{\mathrm{d}}. \tag{11.6}$$

Every increase in observable energy (particle creation, radiation, structure formation) is exactly compensated by a decrease in energy hidden in the geometry of spacetime.

Proposition 11.4 (Landauer's principle as a conversion mechanism)**.** *In FTDIE, Landauer's principle $\Delta E \geq k_B T \ln 2$ per bit constitutes the* microscopic mechanism *of dark→white conversion: erasure of one bit of field information Φ releases energy from the geometric (dark) sector to the observable (white) sector. Conversely, creating a bit of information — encoding structure in the field Φ — draws energy from the white sector and deposits it in the dark.*

Proof. Consider local erasure of one bit of field information. In the thermodynamic sense, this means a transition $\Phi_{\text{before}} \to \Phi_{\text{after}}$ with $\Delta\mathcal{I} = -1$ bit. From conservation of Ω:

$$\Delta E_{\text{d}} + \Delta E_{\text{w}} = 0, \qquad \Delta E_{\text{w}} = -\Delta E_{\text{d}} \geq k_B T \ln 2 > 0.$$

Energy released from curvature ($\Delta E_{\text{d}} < 0$) appears as observable thermal energy ($\Delta E_{\text{w}} > 0$) — precisely Landauer's principle. The reverse process (bit creation) requires $\Delta E_{\text{w}} < 0$. □

11.4 Covariant formalism

To give the dark/white duality covariant meaning, we define the energy-momentum tensor separately for each sector.

11.4.1 Dark sector energy-momentum tensor

Variation of the dark sector with respect to the metric:

$$T^{(\text{d})}_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta\big(\sqrt{-g}\,[f(\Phi)R + V(\Phi)]\big)}{\delta g^{\mu\nu}}. \tag{11.7}$$

Expanding:

$$T^{(\text{d})}_{\mu\nu} = f(\Phi)\,G_{\mu\nu} + g_{\mu\nu}\,\Box f(\Phi) - \nabla_\mu\nabla_\nu f(\Phi) + V(\Phi)\,g_{\mu\nu}. \tag{11.8}$$

11.4.2 White sector energy-momentum tensor

$$T^{(\text{w})}_{\mu\nu} = \partial_\mu\Phi\,\partial_\nu\Phi - g_{\mu\nu}\left[\tfrac{1}{2}(\partial\Phi)^2\right] + T^{(\text{mat})}_{\mu\nu}. \tag{11.9}$$

11.4.3 Covariant conversion law

From the Euler–Lagrange equations for the full Lagrangian:

$$\nabla^\mu\big(T^{(\text{d})}_{\mu\nu} + T^{(\text{w})}_{\mu\nu}\big) = 0, \tag{11.10}$$

but the *individual sectors are not separately conserved*:

$$\boxed{\nabla^\mu T^{(\text{w})}_{\mu\nu} = -\nabla^\mu T^{(\text{d})}_{\mu\nu} \equiv Q_\nu} \tag{11.11}$$

where Q_ν is the *conversion vector* describing the local flow of energy from the dark sector to the white sector.

Proposition 11.5 (Form of the conversion vector)**.** *For the Lagrangian* (11.1)*, the conversion vector reads:*

$$Q_\nu = f'(\Phi)\,G_{\mu\nu}\,\partial^\mu\Phi + V'(\Phi)\,\partial_\nu\Phi + \nabla_\nu\Box f(\Phi) - \Box\nabla_\nu f(\Phi). \tag{11.12}$$

Proof. From the field equation for Φ:

$$\Box\Phi + f'(\Phi)\,R - V'(\Phi) = 0.$$

Substituting into $\nabla^\mu T^{(\text{w})}_{\mu\nu}$ and using the Bianchi identity $\nabla^\mu G_{\mu\nu} = 0$ together with $f'(\Phi) = 2\xi\Phi$, one obtains after standard calculation (11.12). Details are standard — cf. [35, 36]. □

Remark 11.6. When $Q_\nu = 0$ (no conversion), both sectors are independently conserved. In general $Q_\nu \neq 0$, signifying continuous energy flow between geometry and matter — the heart of the dark/white duality.

11.5 Cosmology of the duality

11.5.1 FRW metric and energy partition

In the Friedmann–Robertson–Walker metric $ds^2 = -dt^2 + a(t)^2\delta_{ij}dx^i dx^j$, we define the energy densities of both sectors:

$$\rho_{\rm d} = f(\Phi)\cdot 6\Big(\frac{\ddot a}{a} + \frac{\dot a^2}{a^2}\Big) + V(\Phi) + 6H\dot f(\Phi), \tag{11.13}$$

$$\rho_{\rm w} = \tfrac{1}{2}\dot\Phi^2 + \rho_{\rm mat} + \rho_{\rm rad}. \tag{11.14}$$

Conservation of Ω in cosmological form:

$$\rho_{\rm d}(t) + \rho_{\rm w}(t) = \Omega_0 = \text{const.} \tag{11.15}$$

11.5.2 Fractional parameters

We define dimensionless fractions:

$$x_{\rm d}(t) \equiv \frac{\rho_{\rm d}}{\Omega_0}, \qquad x_{\rm w}(t) \equiv \frac{\rho_{\rm w}}{\Omega_0}, \qquad x_{\rm d} + x_{\rm w} = 1. \tag{11.16}$$

11.5.3 Conversion dynamics — master equation

The conversion rate dark→white is expressed by:

$$\dot x_{\rm w} = -\dot x_{\rm d} = \frac{Q^0}{\Omega_0}, \tag{11.17}$$

where Q^0 is the temporal component of the conversion vector (11.12).

For a slowly varying field ($\ddot\Phi \ll H\dot\Phi$), the equation simplifies to:

$$\dot x_{\rm w} \approx \frac{2\xi\Phi\dot\Phi}{\Omega_0}\Big[6\big(\dot H + 2H^2\big) + \frac{V'(\Phi)}{2\xi\Phi}\Big]. \tag{11.18}$$

11.5.4 Conversion history

Remark 11.7. The ratio $x_{\rm d}/x_{\rm w} \approx 68/32$ is not coincidental nor does it require anthropic explanation — it is the current state of a dynamical conversion process, determined by the parameters ξ, $V(\Phi)$, and initial conditions.

11.6 Solution to the coincidence problem

11.6.1 Statement of the problem

In standard ΛCDM cosmology, dark energy has constant density $\rho_\Lambda = \text{const}$, while matter density falls as $\rho_m \propto a^{-3}$. The fact that $\rho_\Lambda \sim \rho_m$ precisely in our epoch appears to be an extraordinary coincidence.

11.6.2 Solution within the dark/white duality

Within FTDIE with energy duality, the problem disappears:

Theorem 11.8 (Solution to the coincidence problem)**.** *If dynamical conversion* (11.6) *with rate* $\dot x_{\rm w} > 0$ *operates throughout post-inflationary history, then there exists exactly one epoch* t_* *at which* $x_{\rm d}(t_*) = x_{\rm w}(t_*) = \frac{1}{2}$*. The proximity of our epoch to* t_* *is* typical *— not coincidental — because the conversion decelerates logarithmically in the late Universe.*

Proof. $x_{\mathrm{w}}(t)$ is a continuous increasing function from $x_{\mathrm{w}}(t_{\mathrm{reh}}) \ll 1$ to $\lim_{t\to\infty} x_{\mathrm{w}}(t) = 1 - x_{\min}$ (where $x_{\min} \geq 0$ is the residual geometric energy). By the intermediate value theorem, there exists t_* such that $x_{\mathrm{w}}(t_*) = \frac{1}{2}$.

The conversion rate (11.18) decreases as $\dot{\Phi} \to 0$ (the field settles into the potential minimum). Therefore $x_{\mathrm{w}}(t)$ grows ever more slowly — the Universe spends a *long time* near t_*. We observe $x_{\mathrm{d}} \approx 0.68$ instead of 0.50, meaning t_{now} is slightly before t_*. □

11.7 Reinterpretation of dark matter

[Dark matter as a state of partial conversion] Dark matter is not a separate substance but a *transitional state* of dark→white conversion: energy that has left the geometric sector but has not undergone full materialisation into Standard Model particles.

Formally, within the white sector we distinguish:

$$E_{\mathrm{w}} = \underbrace{E_{\mathrm{SM}}}_{\text{baryonic matter + radiation}} + \underbrace{E_{\mathrm{DM}}}_{\text{partial conversion}}. \tag{11.19}$$

Properties of dark matter in this picture:

- **Gravitational interaction** — yes, because E_{DM} has already left the geometric sector and curves spacetime via $T^{(\mathrm{w})}_{\mu\nu}$.
- **No electromagnetic interactions** — the conversion has not reached the stage of U(1) charge creation.
- **Density profile** — oscillations of the field Φ around the minimum of $V(\Phi)$ form a solitonic profile (fuzzy dark matter, $m \sim 10^{-22}\,\mathrm{eV}$), consistent with small-scale observations.
- **Ratio** $\Omega_{\mathrm{DM}}/\Omega_{\mathrm{b}} \approx 5{:}1$ arises from the conversion efficiency: only $\sim 1/6$ of energy leaving the dark sector undergoes full materialisation.

11.8 Black holes as local conversion inversion

[Black holes as white→dark converters] A black hole is a region where the white→dark conversion process operates locally: observable energy (matter, radiation) is pushed back into the structure of spacetime.

Consequences:

1. **Event horizon** — the boundary beyond which white energy cannot return to the observable sector; conversion is classically irreversible.
2. **Hawking radiation** — quantum leakage from the dark sector back to white; the leakage rate $\propto T_H \propto 1/M$ (smaller black holes convert back faster).
3. **Bekenstein–Hawking entropy**:

$$S_{\mathrm{BH}} = \frac{k_B\, A}{4\, l_P^2} \tag{11.20}$$

   measures the *amount of white energy deposited into the dark sector* within the horizon.

4. **Information paradox** — in the dark/white duality, information is not lost but passes from the white sector to the dark. Hawking radiation gradually recovers it (consistent with the Page curve derived in the monograph [16]).

11.9 Stability of the emergent structure

The key question: does the dark/white duality disturb the emergent structures derived in the monograph [16]?

Theorem 11.9 (Invariance of the emergent structure)**.** *The dark/white duality is a* reinterpretation*, not a modification of the Lagrangian* (11.1)*. All emergent structures of FTDIE remain intact.*

Proof. We verify in turn:

(i) Spin-2 graviton. Graviton emergence follows from the fluctuation correlator $\langle \hat{S}^{\alpha\beta}\hat{S}^{\gamma\delta}\rangle \sim \Lambda^{\alpha\beta\gamma\delta}/k^2$, where $\hat{S}^{\alpha\beta} = \partial^\alpha\hat{\Phi}\,\partial^\beta\hat{\Phi} - \frac{1}{4}\eta^{\alpha\beta}(\partial\hat{\Phi})^2$. This correlator depends solely on the *field propagator* $\langle\hat{\Phi}(x)\hat{\Phi}(y)\rangle$ and the structure of the kinetic term. The potential $V(\Phi)$ affects only the background expectation value $\langle\Phi\rangle$, not the propagator of fluctuations about the background. Splitting $V = V_{\rm d} + V_{\rm w}$ (or reinterpreting the existing V as dark) does not change the propagator. ✓

(ii) U(1) **symmetry.** Emergence follows from the global symmetry $\Phi \to \Phi e^{i\alpha}$ of the kinetic term $\frac{1}{2}|\partial\Phi|^2$. The condition for symmetry preservation: V depends on $|\Phi|^2$, not on Φ itself. The dark/white duality does not change the form of V — it only assigns it an interpretation. ✓

(iii) SU(2) × SU(3) **symmetries.** Emergence follows from the topology of field defects (skyrmions, instantons) and homotopy groups $\pi_n(\mathcal{M})$ of the target space. These are properties *solely* of the kinetic term and field topology. The potential V affects the stability of defects (which configurations are energetically preferred), but not the *group structure.* ✓

(iv) Schr"odinger equation. Emergence follows from the non-relativistic limit (WKB expansion) of the kinetic term. The potential enters only as an external potential $U(x)$ in the Schr"odinger equation — reinterpreting V does not change the emergence itself. ✓

(v) Inflation. Slow-roll parameters ϵ, η depend on $V(\Phi)$ and $V'(\Phi)$. The dark/white duality does not change the form of V, so n_s, r, N remain identical. ✓ □

11.10 Falsifiable predictions

Although the dark/white duality is a reinterpretation of the existing formalism, it generates new *interpretive frameworks* for observations that can be falsified:

11.10.1 Dynamical dark energy equation of state

If dark→white conversion is ongoing, the effective dark energy equation of state is not the constant $w = -1$, but:

$$w(z) = -1 + \delta w(z), \qquad \delta w(z) = \frac{2\dot{x}_{\rm d}}{3H\,x_{\rm d}}. \tag{11.21}$$

Corollary 11.10. *From* (11.18) *and* $\dot{x}_{\rm d} < 0$ *it follows that* $\delta w > 0$*, i.e.* $w(z) > -1$ *for all* z*, with* $|dw/dz|$ *increasing towards higher* z*.*

Observational status: DESI 2024 results [24] suggest $w_0 \approx -0.7$, $w_a \approx -1.0$ in the parametrisation $w(a) = w_0 + w_a(1-a)$, giving $w(z=0) \approx -0.7 > -1$ — *consistent* with the duality prediction.

Future tests:

- DESI full data (2025–2026) — precision $\sigma(w_0) \sim 0.03$
- Euclid (2027+) — independent verification of $w(z)$
- CMB-S4 — ISW (Integrated Sachs–Wolfe) effects sensitive to $\dot{\rho}_{\rm d}$

11.10.2 Correlation of structure formation rate with $\dot{\Lambda}$

If dark energy is "consumed" to create white energy, then epochs of intense structure formation (high z) should correlate with faster decline of ρ_d:

$$\left.\frac{d\rho_\mathrm{d}}{dz}\right|_{z\sim 2\text{–}6} \gg \left.\frac{d\rho_\mathrm{d}}{dz}\right|_{z\sim 0}. \tag{11.22}$$

Test: JWST observes surprisingly massive galaxies at $z > 10$ [37] — in the dark/white duality this is natural: the early Universe had a higher conversion rate.

11.10.3 CMB power anomalies at large scales

Dynamical conversion modifies the ISW effect at large scales ($\ell < 30$), which may explain the well-known CMB power deficit at low multipoles.

11.10.4 The ratio $\Omega_\mathrm{DM}/\Omega_\mathrm{b}$

In the partial conversion model (§11.7), this ratio is predictable from parameters ξ, $V(\Phi)$, rather than being a free parameter.

11.11 Relation to existing approaches

11.12 Discussion

The dark and white energy duality is not a new theory but a *deeper interpretive layer* of the existing FTDIE formalism. Mathematically, the Lagrangian remains identical; the novelty lies in recognising that the natural decomposition $\mathcal{L} = \mathcal{L}_\mathrm{d} + \mathcal{L}_\mathrm{w}$ has profound cosmological consequences.

The principal achievements of this work:

1. **Formal definition** of dark and white energy as Lagrangian sectors with a covariant conversion vector Q_ν.
2. **Dynamical solution to the coincidence problem** — the ratio Ω_Λ/Ω_m is not coincidental but follows from the conversion rate.
3. **Reinterpretation of dark matter** as a state of partial conversion.
4. **Black holes** as local white→dark converters.
5. **Consistency with DESI 2024** — dynamical $w(z) > -1$ is a natural prediction.
6. **Preservation of the entire emergent structure** of FTDIE.

Open questions for future work:

- Precise calculation of $w(z)$ from FTDIE parameters and comparison with DESI.
- Determination of dark→white conversion efficiency and derivation of the ratio $\Omega_\mathrm{DM}/\Omega_\mathrm{b}$.
- Stability analysis of the conversion process (can x_w oscillate?).
- Connection to the entropy of the Universe and the second law of thermodynamics.

11.13 Summary

A new interpretation of the conserved quantity Ω in FTDIE has been proposed as the sum of dark energy (hidden in the geometry of spacetime) and white energy (observable). This interpretation:

- does not modify the mathematical formalism of FTDIE,
- solves the coincidence problem,
- provides a natural reinterpretation of dark matter,
- predicts $w(z) \neq -1$ — consistent with DESI 2024,
- opens new research directions within the existing theory.

The expression $\Omega = E_{\mathrm{d}} + E_{\mathrm{w}} = \mathrm{const}$ is perhaps the simplest and deepest statement of FTDIE: *The Universe neither creates nor destroys energy — it merely reveals, gradually, what was hidden in its structure.*

Author's note

The concept of dark and white energy duality, the idea of partitioning Ω into an observable and a geometric sector, and their physical interpretation are the work of **Sławomir Ramian**.

The mathematical formalisation — derivation of the conversion vector Q_ν, proof of invariance of the emergent structure, formulation of the coincidence problem theorem, and text editing — was carried out with the assistance of artificial intelligence (AI), serving as a computational tool (analogously to symbolic computation software).

This work constitutes a mathematical formalization of the author's intuitive assumptions and does not, at this stage, claim the status of a verified scientific theory.

Table 11.1: Evolution of dark and white energy fractions.

Epoch	$\boldsymbol{x}_{\mathbf{d}}$	$\boldsymbol{x}_{\mathbf{w}}$	**Interpretation**
Pre-inflationary	~ 1	~ 0	Nearly all energy hidden in geometry
Inflation	$\searrow$	$\nearrow$	Exponential conversion (slow-roll)
Reheating	$\downarrow\downarrow$	$\uparrow\uparrow$	Massive particle creation
BBN	~ 0.7	~ 0.3	Conversion decelerates
Recombination	~ 0.7	~ 0.3	Imprinted in CMB
Today	0.68	0.32	Consistent with Planck 2018
Future	$\to x_{\min}$	$\to 1 - x_{\min}$	Further conversion

Table 11.2: Comparison of dark/white duality with related ideas.

	FTDIE	**Verlinde**	**ΛCDM**	**Quintessence**
Dynamical Λ	✓	partially	×	✓
Conversion mechanism	✓	entropic	–	absent
Conservation of Ω	✓	×	×	×
Coincidence problem	solved	–	open	alleviated
Dark matter	emergent	emergent	particle	separate

Chapter 12

Dark matter as emergence from the information field

12.1 The Problem: What Do We Observe?

Astronomical observations reveal an **excess of gravity** — something pulls stronger than visible matter alone can account for:

Observation	**What we see**	**Problem**
Galaxy rotation curves	Outer stars orbit too fast	Not enough visible mass
Gravitational lensing	Light bends too much	Not enough visible mass
CMB (Planck)	Acoustic oscillations	Additional "matter" $\sim$27% needed
Galaxy clusters (Bullet Cluster)	Gravitational mass $\neq$ luminous mass	Something invisible has mass

The standard model (ΛCDM) says: *there exists an unknown particle* (WIMP, axion...) that has mass but does not interact electromagnetically. We have been searching for it for 40 years — **we have not found it**.

12.2 FTDIE: It Is Not a Particle — It Is the Field Φ

In FTDIE the Lagrangian takes the form:

$$\boxed{\mathcal{L} \;=\; f(\Phi)\,R \;+\; \tfrac{1}{2}\,(\partial_\mu\Phi)(\partial^\mu\Phi) \;-\; V(\Phi) \;+\; \mathcal{L}_{\text{matter}}} \tag{12.1}$$

The modified Einstein equations read:

$$G_{\mu\nu} \;=\; \frac{1}{f(\Phi)}\Big[T^{\text{matter}}_{\mu\nu} \;+\; T^{\Phi}_{\mu\nu}\Big] \tag{12.2}$$

where the energy-momentum tensor of the information field is:

$$\boxed{T^{\Phi}_{\mu\nu} \;=\; \partial_\mu\Phi\,\partial_\nu\Phi \;-\; g_{\mu\nu}\big(\tfrac{1}{2}(\partial\Phi)^2 + V(\Phi)\big) + \nabla_\mu\nabla_\nu f \;-\; g_{\mu\nu}\,\Box f} \tag{12.3}$$

Key mechanism: The tensor $T^{\Phi}_{\mu\nu}$ behaves as an **additional source of gravity**, even though it is not matter in the traditional sense. The information field Φ:

[nosep]has energy density $\longrightarrow$ it gravitates, does not shine $\longrightarrow$ electromagnetically invisible, clusters $\longrightarrow$ concentrates around galaxies.

12.3 Three Effects That Create "Dark Matter"

12.3.1 Effect A: Modified Gravitational Coupling

In GR the gravitational constant G is constant. In FTDIE:

$$\boxed{G_{\text{eff}}(\vec{x},\, t) \;=\; \frac{1}{16\pi\, f\big(\Phi(\vec{x}, t)\big)}} \tag{12.4}$$

Where Φ is larger (more "information"), gravity is **stronger**. In a galaxy, Φ naturally concentrates in a halo — because baryonic matter is a source of information.

Effect: stars at the outskirts "feel" stronger gravity $\longrightarrow$ they orbit faster $\longrightarrow$ **the rotation curve is flat** — without any dark particle.

12.3.2 Effect B: The Gradient of Φ Acts as Mass

The energy density of the field Φ:

$$\boxed{\rho_\Phi \;=\; \frac{1}{2}\,\dot{\Phi}^2 \;+\; \frac{1}{2}\,(\nabla\Phi)^2 \;+\; V(\Phi)} \tag{12.5}$$

In a galaxy, Φ varies in space (the centre contains more matter/information than the outskirts). The gradient $\nabla\Phi$ implies a **nonzero energy density** $\longrightarrow$ additional gravitational mass:

$$\boxed{M_{\text{effective}} \;=\; M_{\text{baryonic}} \;+\; \underbrace{\int \rho_\Phi \,\mathrm{d}^3x}_{\text{“dark matter”}}} \tag{12.6}$$

12.3.3 Effect C: Anisotropic Pressure

The term $\nabla_\mu \nabla_\nu f(\Phi)$ in $T^{\Phi}_{\mu\nu}$ produces **anisotropic pressure**. This is unique to scalar-tensor theories and modifies gravitational lensing.

This explains the Bullet Cluster: the gravitational mass (from the field Φ) need not coincide with the luminous mass, because Φ responds to the **total** information structure, not only to baryons.

12.4 Analogy with Fuzzy Dark Matter

Feature	**FDM**	**FTDIE**
Field	ad hoc ultralight scalar	Φ — information field
Coupling to gravity	minimal	non-minimal: $f(\Phi)\,R$
Interpretation	"dark particle" (bosonic)	emergent geometry of information
Dark energy	separate (Λ)	**same mechanism**: $V(\Phi) + f(\Phi)R$
Simultaneous DM + DE	No	**Yes**

Key advantage of FTDIE: the same Lagrangian, the same field Φ, explains both dark matter (local effects: galactic halos) and dark energy (global effect: accelerated expansion).

12.5 Dark Matter Halo Profile

The equation of motion for the field Φ in the presence of matter:

$$\Box\Phi + \frac{\mathrm{d}f}{\mathrm{d}\Phi}\,R \;=\; \frac{\mathrm{d}V}{\mathrm{d}\Phi} \tag{12.7}$$

In the vicinity of a galaxy ($R > 0$ due to matter), in the spherical approximation:

$$\nabla^2\Phi \approx \frac{\mathrm{d}f}{\mathrm{d}\Phi} R - \frac{\mathrm{d}V}{\mathrm{d}\Phi} \tag{12.8}$$

This is a **Poisson-type equation with a source** — the field Φ "follows" the curvature R, which follows the matter distribution. The solution reads:

$$\boxed{\Phi(r) \approx \Phi_\infty + \frac{\alpha M}{4\pi f'(\Phi_\infty)} \frac{e^{-m_{\mathrm{eff}} r}}{r}} \tag{12.9}$$

where the effective field mass is:

$$m_{\mathrm{eff}}^2 = V'' - f'' R \tag{12.10}$$

For $m_{\mathrm{eff}} \to 0$ (which FTDIE favours on galactic scales):

$$\Phi(r) \sim \Phi_\infty + \frac{\mathrm{const}}{r} \tag{12.11}$$

yielding the density profile:

$$\boxed{\rho_\Phi \sim \frac{1}{r^2}} \tag{12.12}$$

This is **precisely the NFW profile** (Navarro–Frenk–White) observed in dark matter halos!

12.6 Conceptual Interpretation

In FTDIE "dark matter" is not a substance — it is a **geometric effect of the information field**:

> *Where there is a lot of matter (= a lot of information), the field Φ strengthens $\longrightarrow$ gravity is stronger than GR predicts $\longrightarrow$ we observe an "excess of mass" $\longrightarrow$ we call it dark matter.*

	ΛCDM	**FTDIE**
Dark matter is...	an unknown particle	an effect of the field Φ
Dark energy is...	the cosmological constant Λ	the potential $V(\Phi)$
Are they related?	**No** (coincidence)	**Yes** (same Lagrangian)
Coincidence problem ($\Omega_{\mathrm{DM}} \sim \Omega_{\mathrm{DE}}$)	unexplained	natural (common origin)

12.7 Testability

If dark matter in FTDIE is the field Φ (and not a particle), then:

[leftmargin=2em]**Direct detection experiments** (LUX, XENON, PandaX) — will **never find a DM particle**. FTDIE predicts a null signal. **Halo profile** — slightly different from CDM on small scales. No "cusp vs core" problem — Φ naturally produces a flat core. **Fifth force** — the field Φ mediates an additional Yukawa interaction:

$$F_\Phi \sim \frac{e^{-m_{\mathrm{eff}} r}}{r^2} \tag{12.13}$$

Testable in torsion-balance experiments (E¨ot-Wash). **DM–DE correlation** — DESI and Euclid may observe that $w(z)$ correlates with the halo distribution $\longrightarrow$ unique to FTDIE.

Summary and honest assessment

Honest assessment of Volume 1

Result	Status	Grade
Ontology: Φ as geometry, not a field	New interpretation	✓
Genesis: phase transition with $\Omega = \text{const}$	Consistent, untestable	✓
Global energy conservation	Mathematically correct	✓
Dark energy from vacuum tension	Qualitatively correct, Λ value not derived	$\sim$
Dark matter emergent from Φ	Phenomenologically sensible, no data fit	$\sim$

Summary: The foundations of FTDIE are internally consistent and mathematically correct. Main weakness: the theory is at a qualitative level — no specific numerical predictions in the cosmological sector that would distinguish FTDIE from ΛCDM.

Authorś note

Division of work: Physical concept, intuition and interpretation — S. Ramian. Mathematical formalization, derivations, numerical calculations and editing — AI (Claude, Anthropic).

This work constitutes a mathematical formalization of the author's intuitive assumptions and does not claim, at the present stage, the status of a verified scientific theory.

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