Temporal–Density Framework (Volume 3): Entropy Gradients, Dark–Matter Compression, and Cosmic Structure

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Abstract

Volume 3 of the Temporal–Density Framework extends the dimensionless triad $\alpha c \lambda = 1$ to the cosmological domain by showing that the fixed 5:1 compression imbalance between dark (3) curvature cores and baryonic (2) → (1) reactive matter inevitably generates a global entropy gradient throughout cosmic history.

Dark matter forms the non–reactive compression sector of the temporal substrate; baryons alone provide transverse electromagnetic response. This asymmetry produces a universal compression–reaction differential that governs the emergence of large–scale structure, drives the persistent morphology of galaxies, and leaves coherence signatures in the CMB. The gradient arises not from additional fields or dark–energy components, but from the intrinsic reaction structure of the temporal medium established in Volumes 1 and 2.

The framework developed here yields a unified explanation of:

- the primordial 5:1 dark–to–baryonic curvature partition as an entropic boundary condition of the gauge cascade;
- galactic asymmetries as baryonic overreaction to surrounding non–reactive (3) curvature wells;
- CMB anisotropies as a coherence map of the primordial (2) relaxation field;
- accelerated black–hole growth as the long–timescale accumulation of curvature into non–radiative (1) horizon states.

Cosmic structure, horizon evolution, and large–scale acceleration therefore emerge as macroscopic expressions of the same temporal–density substrate that governs particle cores, gauge symmetry, and radiation behaviour. The entropy gradient formalised in this volume completes the foundational architecture of the Temporal–Density Framework by linking its microscopic derivations to the full cosmological evolution of the universe.

Contents

1 Introduction

Volume 3 of the Temporal–Density Framework (TDFT) addresses the final structural element required for a complete cosmological formulation: the global entropy gradient generated by the fixed compression imbalance between dark SU(3) curvature cores and baryonic $\mathrm{SU}(2) \to \mathrm{U}(1)$ reactive matter. Where Volume 1 established the invariant

$$\alpha c \lambda = 1$$

and demonstrated that gravitational curvature, electromagnetism, and gauge coherence are projections of a single temporal substrate, and Volume 2 traced the emergence of baryons, dark matter, and horizons through the $\mathrm{SU}(3) \to \mathrm{SU}(2) \to \mathrm{U}(1)$ cascade, the present volume extends the framework to the dynamical and thermodynamic evolution of the universe itself.

The motivation is twofold. First, the universe contains a permanent compression asymmetry: dark SU(3) inclusions carry five times the intrinsic temporal curvature of baryonic matter, yet only baryons possess a transverse electromagnetic reaction mode. This mismatch generates an irreversible entropy gradient that influences morphology, large-scale flows, and the coherence structure of the CMB. Second, several longstanding puzzles—dark-matter geometry, the absence of annihilation pathways, horizon behaviour, CMB anisotropies, apparent late-time acceleration, and the rapid appearance of supermassive black holes—follow directly once this gradient is made explicit within the temporal field equations.

The purpose of Volume 3 is therefore to develop the *dynamical consequences* of the temporal-density substrate: how compression is redistributed, how dilation is resisted, how structure organises itself in the presence of asymmetric reaction modes, and how the cosmos evolves under the joint influence of dark-matter compression and baryonic electromagnetic overreaction. A central outcome is that many observational features normally treated as independent phenomena emerge as coupled responses of the same underlying substrate.

Scope and Structure of this Volume

The volume is organised as follows:

1. **The Global Entropy Gradient in TDFT.** We derive the universal compression imbalance and its role in the temporal field equations.
2. **Dark–Matter Geometry and the Compression Field.** Persistent, non-reactive SU(3) cores define the background compression landscape that shapes baryonic dynamics.
3. **Electromagnetism as the Transverse Reaction Field.** Building on the intrinsic definition of U(1) rotation, we show that baryons necessarily over-react to surrounding curvature gradients.
4. **Cosmic Structure as Compression–Reaction Equilibrium.** Galaxies, disks, spirals, bars, and cluster-scale structures arise as reaction-driven equilibria anchored by the compression field.
5. **The CMB as an SU(2) Coherence Map.** The CMB anisotropy pattern is interpreted as a fossil imprint of the primordial SU(2) relaxation domain.
6. **Horizon Growth and Global Constraints.** Using the non-radiative behaviour of black holes established in Volume 2, we analyse the contribution of horizon growth to the long-term entropic imbalance.
7. **Predictions and Observational Signatures.** We derive the quantitative consequences: halo geometry, rotation asymmetry, baryon–compression coupling, CMB correlations, and mass-growth asymmetries in non-radiative horizons.

This structure completes the architectural triad of the Temporal–Density Framework: the invariant relation of Volume 1, the gauge-cascade foundations of Volume 2, and now the global entropy gradient that governs cosmic evolution in Volume 3.

2 The Global Entropy Gradient in TDFT

2.1 What Entropy Means in the Temporal–Density Framework

In conventional thermodynamics, entropy measures microscopic disorder or the number of inaccessible microstates. In the Temporal–Density Framework, the concept is fundamentally different: entropy quantifies the *distribution of temporal compression* across the substrate and the differing capacities of gauge sectors to react to that compression.

Dark SU(3) cores carry longitudinal temporal compression but possess no electromagnetic or weak reaction modes. Baryonic matter, by contrast, inherits full SU(2) $\to$ U(1) transverse reactivity, enabling it to respond to compression through electromagnetic rotation. The fixed 5:1 ratio between non-reactive compression (dark matter) and reactive compression (baryons) therefore defines a global, irreversible *compression–reaction differential* built into the structure of the substrate.

In TDFT, entropy is the macroscopic expression of this differential. Regions dominated by dark compression accumulate curvature that cannot redistribute itself, while baryonic regions necessarily overreact, generating electromagnetic structure, radiation, and morphological asymmetry. Cosmic evolution is thus governed by the continual transfer of compression into domains with different reaction capacities.

Accordingly, entropy in the Temporal–Density Framework is not a measure of microscopic randomness but of the *geometric mismatch* between the sectors that generate temporal compression and the sectors capable of reacting to it. This geometric mismatch is the origin of the universal gradient that shapes galaxies, clusters, CMB coherence, and the long-term evolution of horizons.

2.2 Temporal Compression and Electromagnetic Reaction

The temporal substrate supports two fundamental modes of response: a *longitudinal* mode associated with curvature (governed by the linear–density constant λ), and a *transverse* mode associated with rotational reactivity (governed by the intrinsic temporal–electromagnetic impedance). In the dimensionless formulation established in Volume 1, these modes are encoded by the substrate stiffness γ, the normaliser ξ, and the intrinsic impedance $Z_t = \sqrt{\mu_t/\varepsilon_t}$:

$$\alpha = \frac{\gamma}{c}, \qquad \lambda = \frac{1}{\gamma c}, \qquad Z_0 = \xi Z_t. \tag{1}$$

Thus longitudinal compression is controlled by λ, while transverse electromagnetic response is controlled by Z_t; both derive from the same underlying temporal stiffness γ.

Longitudinal response. Spatial gradients of the temporal potential $\tau(x)$ generate curvature, with the realised fractional density

$$\chi(x) = \frac{M/R}{\lambda} \tag{2}$$

measuring local compression as a dimensionless fraction of the triad scale. The curvature equation of the temporal substrate, derived from $\alpha c \lambda = 1$ [1], shows that increasing χ stiffens the longitudinal response:

$$\gamma_{\text{eff}}(x) = \frac{\gamma}{\sqrt{1-\chi(x)}}, \qquad 0 \le \chi < 1, \tag{3}$$

with the divergence at $\chi \to 1^-$ defining the U(1) temporal floor [2].

Transverse response. Electromagnetism arises when the temporal potential supports rotational modulation rather than compression. Projecting the temporal fields through the normaliser ξ recovers the intrinsic Maxwell system [1]:

$$\nabla \times B_t = \frac{1}{c^2}\,\partial_t E_t, \qquad \nabla \times E_t = -\partial_t B_t. \tag{4}$$

The corresponding energy flux is

$$S_t = \frac{1}{\mu_t}\,E_t \times B_t, \tag{5}$$

showing that electromagnetic activity is a *transverse redistribution of temporal density.* Its magnitude is fixed by the intrinsic impedance $Z_t = \sqrt{\mu_t/\varepsilon_t}$, with $Z_0 = \xi Z_t$ giving its SI presentation.

Compression–reaction coupling. Combining longitudinal stiffness and transverse impedance yields a unified expression for baryonic response to background compression. Increasing χ enhances the longitudinal stiffness γ_{eff}, while the transverse impedance Z_t remains fixed:

$$\frac{\text{transverse response}}{\text{longitudinal compression}} = \frac{Z_t}{\gamma_{\text{eff}}(x)} = Z_t\sqrt{1-\chi(x)}. \tag{6}$$

As curvature deepens ($\chi \uparrow$), the longitudinal mode becomes stiffer, but the transverse mode does not scale with it. Baryonic matter therefore reacts *more strongly* to a given compression gradient than the substrate can accommodate, generating an intrinsic over-reaction channel.

This asymmetry is the mathematical origin of the *compression–reaction differential* that drives entropy production in TDFT. Dark SU(3) inclusions contribute compression without transverse reaction, while baryons contribute both. The fixed proportion between these contributions—the primordial 5:1 curvature partition derived in [2]—sets the global entropy gradient developed throughout this volume.

2.3 Dark Matter as Compression Without Reaction

Dark SU(3) domains constitute the non–reactive sector of the temporal substrate. In the gauge cascade developed in Volume 2, SU(3) coherence collapses into pure longitudinal temporal compression with no accompanying transverse degrees of freedom:

$$\text{SU}(3) \;\longrightarrow\; \text{longitudinal compression only.} \tag{7}$$

Thus dark matter contributes curvature through its realised density χ_{dm}, but possesses *no electromagnetic or weak channels* through which this compression could be redistributed, radiated, or relaxed.

Purely longitudinal contribution. Let $\chi_{\text{dm}}(r)$ denote the fractional realised density generated by a dark SU(3) core at radius r:

$$\chi_{\text{dm}}(r) = \frac{M_{\text{dm}}/r}{\lambda}, \tag{8}$$

where λ is the universal linear–density constant of the triad. Because SU(3) sectors lack transverse degrees of freedom, the curvature associated with χ_{dm} modifies only the longitudinal stiffness:

$$\gamma_{\text{eff}}(r) = \frac{\gamma}{\sqrt{1-\chi_{\text{dm}}(r)}}, \tag{9}$$

with the limit $\chi_{\text{dm}} \to 1$ giving the non–radiative U(1) temporal floor [2]. Crucially, in the absence of a transverse mode, this increased stiffness cannot relax or redistribute itself and is therefore permanent.

Absence of reaction channels. In the SU(2) → U(1) sector, compression can be relieved through transverse rotation of the temporal fields, encoded by the intrinsic impedance:

$$Z_t = \sqrt{\mu_t/\varepsilon_t}. \tag{10}$$

Volume 1 shows that this mechanism underlies electromagnetic reactivity, enabling baryons to redistribute temporal density through radiation and angular momentum exchange. Dark matter, fixed in the SU(3) sector, has no such channel:

$$\text{dark matter}: \qquad \partial_t \chi_{\text{dm}} = 0, \quad \nabla \times E_t = 0, \quad \nabla \times B_t = 0. \tag{11}$$

The realised compression is therefore strictly longitudinal and strictly non–radiative.

Irreversible contribution to the entropy gradient. Because dark SU(3) compression cannot dissipate, the curvature it produces acts as an irreversible source term in the global entropy gradient of the universe. Dark–dominated regions become progressively stiffer, while baryonic regions retain the ability to respond transversely. The fixed proportion between these sectors—five units of non–reactive compression for every unit of reactive compression, as derived in Volume 2—yields

$$\frac{\chi_{\text{dm}}}{\chi_{\text{b}}} = 5:1, \tag{12}$$

establishing the global imbalance central to this volume. Dark matter therefore defines the non–reactive curvature landscape that anchors baryonic evolution and shapes the geometry of the temporal substrate throughout cosmic history.

2.4 Baryons as Over–Reactive U(1) Modes

Where dark SU(3) domains provide only longitudinal compression, baryonic matter resides in the SU(2) → U(1) sector where transverse reaction modes are fully available. The U(1) projection endows baryons with a fixed transverse impedance Z_t and a Maxwell–like reaction channel capable of redistributing temporal density through rotation and radiation. As a result, baryons are inherently *over–reactive* relative to the longitudinal stiffness imposed by surrounding non–reactive dark compression.

Transverse reactivity from the U(1) projection. Volume 1 showed that the intrinsic electromagnetic fields (E_t, B_t) arise as rotational projections of the temporal potential and satisfy the intrinsic Maxwell system:

$$\nabla \times B_t = \frac{1}{c^2}\,\partial_t E_t, \qquad \nabla \times E_t = -\partial_t B_t, \tag{13}$$

with associated energy flux

$$S_t = \frac{1}{\mu_t}\,E_t \times B_t. \tag{14}$$

These fields are governed by the fixed transverse impedance

$$Z_t = \sqrt{\mu_t/\varepsilon_t}, \tag{15}$$

and their SI expression via $Z_0 = \xi Z_t$ [1]. Thus baryons possess a built–in mechanism through which local compression can be relieved by transverse redistribution of temporal density.

Over–reaction in compression gradients. The baryonic response to a local compression $\chi(x)$ is determined by the compression–reaction ratio derived in Section 2.2:

$$\mathcal{R}(x) = \frac{Z_t}{\gamma_{\text{eff}}(x)} = Z_t\sqrt{1-\chi(x)}. \tag{16}$$

As the realised density χ increases, the longitudinal stiffness γ_{eff} grows, whereas the transverse impedance Z_t remains fixed. This produces a structural imbalance: baryons retain their full transverse reactivity even as the substrate stiffens.

For any region with $\chi > 0$, we therefore have

$$\frac{\text{transverse response}}{\text{longitudinal stiffness}} = Z_t\sqrt{1-\chi(x)} < Z_t, \tag{17}$$

showing that the baryonic transverse channel always dominates over the stiffening of the substrate. Baryons are thus intrinsically over–reactive relative to the background curvature.

Consequences of over–reactivity. This structural feature produces several unavoidable behaviours:

- **Baryonic overshoot.** Baryons overreact to curvature generated by dark matter, producing strong electromagnetic structure (disks, spirals, bars).
- **Shear sensitivity.** Baryonic distributions respond sharply to even small anisotropies in the surrounding compression field.
- **Energy export.** Radiation and rotational modulation of (E_t, B_t) allow baryons to shed energy and angular momentum.
- **Faster relaxation.** Baryons relax on electromagnetic timescales; dark matter does not, generating a persistent reaction lag.

Rather than smoothing the compression landscape, baryons amplify its geometric structure. The over–reactive U(1) mode therefore forms the reactive half of the compression–reaction differential responsible for the global entropy gradient.

Coupling to the global imbalance. When combined with the non–reactive behaviour of dark SU(3) domains, the baryonic over–response yields the fixed structural inequality

$$\chi_{\text{dm}} = 5\,\chi_{\text{b}}, \tag{18}$$

with baryons supplying all transverse reactivity. This compression–reaction mismatch provides the physical basis for the universal entropy gradient developed in Section 2.5.

2.5 The Universal 5:1 Imbalance as an Entropy Gradient

The global entropy gradient of the universe arises from a single structural feature of the temporal substrate: the fixed 5:1 imbalance between non–reactive SU(3) compression and reactive SU(2) $\to$ U(1) compression. Volume 2 showed that this ratio follows directly from the gauge–cascade geometry: SU(3) triplets contribute five times the realised curvature per coherence radius compared to SU(2) baryonic modes, owing to their larger coherence window and the absence of transverse reaction channels. The imbalance is therefore not a contingent matter–distribution effect but a built–in boundary condition of the substrate.

Compression budget of the gauge cascade. Let $\chi_{\rm dm}$ denote the realised fractional density from SU(3) cores and $\chi_{\rm b}$ the contribution from baryons. From the curvature windows of the cascade (Volume 2), we obtain

$$\frac{\chi_{\rm dm}}{\chi_{\rm b}} = \frac{\Delta r_{\rm SU(3)}}{\Delta r_{\rm SU(2)}} = 5, \tag{19}$$

where Δr_G is the curvature–contributing coherence interval of gauge group G. Since both sectors are fixed by the invariant triad $\alpha c \lambda = 1$ of Volume 1, no later dynamical or cosmological process can alter this ratio.

Reactive vs. non–reactive sectors. The baryonic SU(2) → U(1) sector retains the transverse electromagnetic reaction channel. Its response to compression is governed by the compression–reaction ratio

$$\mathcal{R}(x) = \frac{Z_t}{\gamma_{\rm eff}(x)}, \tag{20}$$

where Z_t is the intrinsic transverse impedance and $\gamma_{\rm eff}$ is the local longitudinal stiffness. Dark SU(3) domains, contributing only to $\gamma_{\rm eff}$ and not to Z_t, supply compression that cannot be redistributed or radiated. The global curvature budget is therefore

$$\chi_{\rm total} = \chi_{\rm dm} + \chi_{\rm b} = 6\chi_{\rm b}, \tag{21}$$

while only the $\chi_{\rm b}$ component possesses reactivity.

Entropy as compression–reaction differential. The entropy gradient of the temporal substrate reflects the imbalance between compression that *cannot* be reacted to and compression that *can*. A schematic measure of this imbalance is

$$\nabla S \;\propto\; \nabla(\chi_{\rm dm} - \mathcal{R}\chi_{\rm b}), \tag{22}$$

which, using $\chi_{\rm dm} = 5\chi_{\rm b}$, becomes

$$\nabla S \;\propto\; \nabla((5 - \mathcal{R})\,\chi_{\rm b}), \tag{23}$$

with $0 < \mathcal{R} < 1$ on all astrophysical scales. Since $(5 - \mathcal{R}) > 4$ universally, the entropy gradient is *strictly positive*: compression accumulates in the non–reactive sector faster than it can be redistributed by baryons.

Cosmological implication. Because the 5:1 ratio is rooted in the geometry of the gauge cascade rather than in cosmological initial conditions, the resulting entropy gradient is a fundamental property of the temporal substrate. It governs:

- the irreversible accumulation of curvature in dark–matter–dominated regions;
- the persistent overreaction of baryons to fixed compression wells;
- the emergence of structure as a relaxation map of the imbalance;
- the long–lived morphological features of galaxies (bars, spirals, warps);
- the imprint of primordial SU(2) relaxation in the CMB.

Thus the universal 5:1 compression ratio is not merely a mass fraction but the fundamental *entropy boundary condition* of the Temporal–Density Framework. It sets the irreversible direction of cosmic evolution and underpins the large–scale phenomena analysed in the sections that follow.

2.6 Relation to Relaxation of the Temporal Substrate

The entropy gradient generated by the universal 5:1 compression imbalance acts directly on the temporal substrate, driving a long–term relaxation process. In TDFT, relaxation is not a thermodynamic redistribution of microstates but a geometric rebalancing of temporal compression between domains with different reaction capacities. Non–reactive SU(3) regions store curvature indefinitely, while baryonic U(1) modes react transversely to even small compression gradients. The substrate therefore evolves by transferring curvature from reactive to non–reactive sectors.

Relaxation as stiffness rebalancing. Let $\gamma_{\text{eff}}(x)$ denote the local longitudinal stiffness of the temporal substrate. From Section 2.3,

$$\gamma_{\text{eff}}(x) = \frac{\gamma}{\sqrt{1-\chi(x)}}, \tag{24}$$

where $\chi(x)$ includes contributions from both baryons and dark matter. Dark–matter–dominated regions exhibit larger χ and therefore greater γ_{eff}. Because baryons possess fixed transverse impedance Z_t (Section 2.4), the substrate preferentially exports curvature into the stiffer, non–reactive domains:

$$\partial_t \gamma_{\text{eff}}(x) > 0 \qquad \text{in dark–matter–dominated regions.} \tag{25}$$

This monotonic growth reflects the fundamental asymmetry: dark compression accumulates curvature; baryons dissipate it.

Relaxation as differential flow of compression. The relaxation pathway can be expressed schematically as

$$\text{reactive sector} \xrightarrow{\text{compression export}} \text{non–reactive sector.} \tag{26}$$

Baryons export curvature through electromagnetic reaction, radiative loss, and angular–momentum redistribution. Dark SU(3) wells, lacking transverse channels, accumulate this imported curvature. Thus,

$$\partial_t \chi_{\text{b}} < 0, \qquad \partial_t \chi_{\text{dm}} > 0, \tag{27}$$

even though χ_{dm} does not evolve through any intrinsic degrees of freedom. Its increase is solely the result of curvature imported from reactive regions.

Irreversibility and time asymmetry. Because Z_t is fixed while γ_{eff} increases with realised compression, the compression–reaction ratio

$$\mathcal{R}(x) = \frac{Z_t}{\gamma_{\text{eff}}(x)} \tag{28}$$

decreases wherever relaxation occurs:

$$\partial_t \mathcal{R}(x) < 0 \qquad \Longleftrightarrow \qquad \partial_t S(x) > 0. \tag{29}$$

This behaviour encodes an intrinsic time asymmetry: regions of initially moderate curvature evolve toward greater stiffness, while low–curvature regions remain reactive and dissipative. The entropy gradient is therefore expressed directly in the evolution of $\mathcal{R}(x)$.

Cosmological–scale consequences. The relaxation of the temporal substrate produces several observable large–scale effects:

- **Outward baryonic drift**, producing characteristic disk–halo offsets in galaxies.
- **Irreversible deepening of dark cores**, as curvature accumulates in non–reactive domains.
- **Bulk flows and large–scale motions** aligned with compression gradients.
- **CMB coherence features** tracing early SU(2)–to–U(1) relaxation.
- **Biased horizon growth**, with black holes acting as additional non–reactive curvature sinks at late times.

Summary. Relaxation of the temporal substrate is the macroscopic expression of the compression–reaction differential. Because dark matter cannot react and baryons over–react, curvature is irreversibly transferred into the non–reactive sector. This defines the entropy gradient, drives structure formation, and sets the global asymmetry that underlies the cosmic architecture developed in the next sections.

3 Dark–Matter Geometry and the Compression Field

3.1 SU(3) Cores as Persistent Curvature Wells

Dark–matter domains originate from the collapse of SU(3) coherence in the primordial gauge cascade. As shown in Volume 2, the SU(3) sector supports longitudinal compression but no transverse rotational modes; when the symmetry breaks to SU(2), the remnant SU(3) fragments retain this purely compressive character. These fragments form the non–reactive curvature wells that constitute the backbone of cosmic structure.

Longitudinal curvature from SU(3) coherence. Let $\rho_{\mathrm{SU(3)}}(r)$ denote the effective temporal–density profile of an SU(3) core. The realised fractional density follows from the linear–density normalisation (Volume 1):

$$\chi_{\mathrm{dm}}(r) = \frac{M_{\mathrm{SU(3)}}(r)/r}{\lambda}, \tag{30}$$

where $M_{\mathrm{SU(3)}}(r)$ is the enclosed SU(3) compression mass and $\lambda = c^2/(2G)$ is the universal linear–density constant. Because SU(3) coherence collapses without generating any transverse reaction channels, the resulting curvature is strictly longitudinal.

The associated stiffness of the temporal substrate is

$$\gamma_{\mathrm{eff}}(r) = \frac{\gamma}{\sqrt{1-\chi_{\mathrm{dm}}(r)}}, \tag{31}$$

with γ the bare temporal stiffness (Volume 1). Thus γ_{eff} increases monotonically toward the centre of the SU(3) domain, reflecting the purely compressive origin of dark structure.

Persistence and non-dissipation. The defining property of an SU(3) core is that it cannot dissipate or redistribute the curvature it generates. Unlike the U(1) sector, which admits transverse electromagnetic reaction with impedance Z_t [1], the SU(3) domain possesses no rotational degrees of freedom and no radiative pathways. Consequently,

$$\partial_t \chi_{\mathrm{dm}}(r) = 0 \quad \Rightarrow \quad \partial_t \gamma_{\mathrm{eff}}(r) = 0 \qquad \text{(intrinsically)}. \tag{32}$$

The curvature profile of an SU(3) core is therefore *locked in* unless external reactive regions (i.e. baryons) export curvature toward it. The SU(3) sector thus provides a persistent curvature scaffold on which cosmic structure assembles.

Geometric influence and curvature anchoring. A persistent SU(3) well defines a region where longitudinal stiffness increases steeply with decreasing radius. Any reactive sector coupled to such a well exhibits characteristic structural responses:

- Increasing transverse overreaction of baryons as γ_{eff} rises (Section 2).
- Flattened orbits and thin disks aligned with steep compression gradients.
- Spiral and bar modes tracing eigen-directions of the curvature Hessian $\nabla\nabla\chi_{\text{dm}}$.
- Large-scale baryonic morphology reflecting the anisotropy of the dark well rather than the baryonic mass distribution.

Because SU(3) cores cannot relax their curvature, they serve as *persistent anchors* for baryonic dynamics. This is why galaxies retain long-lived structures, why rotation curves remain stable over gigayear timescales, and why observed morphology follows the dark compression geometry.

Cluster-scale consequences. In galaxy groups or clusters, multiple SU(3) domains coexist. The composite curvature field is therefore a superposition of persistent wells, none of which can dissipate. The temporal substrate develops long-range gradients of effective stiffness, producing inter-halo tension fields. These tension fields set the stage for the large-scale morphology developed in Section 3.2.

3.2 Why Compression Cannot Dissipate or Radiate

The defining feature of dark SU(3) domains is that the curvature they generate cannot be redistributed, dissipated, or radiated. This follows directly from the gauge structure of the temporal substrate. When primordial SU(3) coherence collapses into the SU(2)$\to$U(1) cascade (Volume 2), all transverse rotational degrees of freedom vanish in the surviving SU(3) fragments. What remains is a purely longitudinal compression mode with no reactive channels.

Absence of transverse degrees of freedom. In Volume 1, the transverse reaction in the U(1) sector was shown to arise from the intrinsic electromagnetic fields (E_t, B_t), governed by the intrinsic Maxwell system:

$$\nabla \times B_t = \frac{1}{c^2}\,\partial_t E_t, \qquad \nabla \times E_t = -\partial_t B_t. \tag{33}$$

The associated Poynting flux,

$$S_t = \frac{1}{\mu_t} E_t \times B_t, \tag{34}$$

encodes the transverse redistribution of temporal density.

SU(3) domains possess no U(1) projection of the temporal fields, and therefore:

$$E_t = 0, \qquad B_t = 0 \qquad \text{in the SU(3) sector.} \tag{35}$$

No rotational modulation and no transverse reaction channel exist.

Longitudinal compression as the only surviving mode. With transverse channels absent, the only degree of freedom remaining is the longitudinal compression encoded in the realised density:

$$\chi_{\text{dm}}(r) = \frac{M_{\text{SU(3)}}(r)/r}{\lambda}, \tag{36}$$

with $\lambda = c^2/(2G)$ the universal linear–density constant (Volume 1). Since SU(3) regions cannot respond transversely, the longitudinal compression cannot be relieved:

$$\partial_t \chi_{\rm dm}(r) = 0. \tag{37}$$

This expresses that no internal mechanism of the SU(3) domain can reduce or redistribute curvature.

No radiative pathway. In the reactive sector, the transverse impedance

$$Z_t = \sqrt{\mu_t/\varepsilon_t} \tag{38}$$

sets the scale for electromagnetic redistribution. Without E_t or B_t, the Poynting vector vanishes:

$$S_t = 0 \qquad \text{(no radiative flux)}. \tag{39}$$

Thus curvature deposited into an SU(3) core remains permanently confined.

Implications for the temporal substrate. The non-dissipative nature of SU(3) compression produces three immediate consequences:

- **Curvature accumulates irreversibly** inside SU(3) wells, since no channel exists to relax it.
- **The effective stiffness increases monotonically** toward the core, following $\gamma_{\rm eff} = \gamma/\sqrt{1-\chi_{\rm dm}}$, reinforcing the curvature profile.
- **Reactive sectors become progressively strained** as baryons over-respond to curvature wells that cannot be smoothed.

Persistent curvature wells. These properties make SU(3) remnants the most stable geometric structures in the universe. Galaxies, clusters, and filaments inherit their shape from these persistent compression wells, not from their baryonic content. Because the SU(3) sector cannot dissipate or radiate away its curvature contribution, its geometry becomes the fixed background against which all subsequent baryonic evolution unfolds.

This intrinsic persistence forms the basis for the asymmetric influence developed in the next subsection.

3.3 Asymmetric Influence on Baryonic Structure

Because dark SU(3) cores contribute persistent longitudinal curvature, while baryons occupy the fully reactive U(1) sector, the two components interact *asymmetrically* with the temporal substrate. SU(3) curvature is fixed and cannot be redistributed; baryons retain full transverse reactivity with a constant impedance Z_t. This mismatch forces baryons to trace, amplify, and stabilise the geometry set by the SU(3) curvature wells.

Curvature gradients and baryonic sensitivity. Let

$$\chi_{\rm dm}(r) = \frac{M_{\rm SU(3)}(r)/r}{\lambda}, \qquad \gamma_{\rm eff}(r) = \frac{\gamma}{\sqrt{1-\chi_{\rm dm}(r)}},$$

denote the realised density and induced longitudinal stiffness of an SU(3) core. Because $\gamma_{\rm eff}$ increases monotonically toward the core and cannot relax, baryons encounter a static but steepening curvature gradient.

The transverse response is governed by the fixed impedance Z_t through

$$\mathcal{R}(r) = \frac{Z_t}{\gamma_{\text{eff}}(r)} = Z_t\sqrt{1-\chi_{\text{dm}}(r)}.$$

As χ_{dm} rises, $\mathcal{R}$ decreases, meaning that the baryonic response becomes proportionally stronger in regions of greater stiffness. Even modest curvature gradients in χ_{dm} generate large transverse reactions.

Forced geometric tracing. Because SU(3) curvature cannot dissipate or radiate (Section 3.2), its geometry is fixed. Baryons therefore adjust their configuration to minimise transverse stress within an immovable curvature landscape. This produces several characteristic features:

- **Disk formation:** orbits flatten along equipotential surfaces of χ_{dm} where stiffness gradients are shallowest.
- **Spiral structure:** shearing in the reaction field amplifies small anisotropies in the curvature Hessian $\nabla\nabla\chi_{\text{dm}}$.
- **Bars:** along stretched principal axes of the curvature field, baryonic over-reaction becomes directionally amplified.
- **Warps and lopsidedness:** asymmetric contributions from neighbouring SU(3) domains introduce distortions with no restoring force from the non-reactive sector.
- **Halo tracing:** the baryonic distribution settles into a configuration that mirrors the fixed SU(3) geometry, producing the observed disk–halo alignment.

These behaviours arise naturally from the compression–reaction differential, with no need for additional phenomenological feedback or exotic interactions.

Sustained asymmetry and long-term stability. Because SU(3) curvature wells persist, the baryonic structures they induce remain stable over gigayear timescales. Baryons continually export curvature through radiation and angular momentum redistribution, but the SU(3) wells retain their shape. This produces a long-lived structural asymmetry:

$$\nabla\gamma_{\text{eff}}(r) \neq 0 \qquad \text{across the baryonic disk.}$$

The tension between a reactive U(1) sector and a non-reactive SU(3) sector naturally explains the longevity of spiral arms, the persistence of bars, and the geometric alignment of baryonic components with the dark–matter curvature field.

Cluster-scale extension. In environments where multiple SU(3) cores coexist—such as galaxy clusters—their persistent curvature wells superpose to form a composite stiffness landscape. The resulting large-scale tension fields extend across inter-halo regions. Baryons respond by forming bridges, filaments, and bulk flows that trace this fixed geometry, mirroring the underlying SU(3) curvature network.

This asymmetric coupling between reactive and non-reactive sectors sets the stage for the explicit geometric signatures analysed in the next subsection.

3.4 Geometric Signatures: Bars, Spirals, Warps, and Halo Shape

The persistent curvature wells generated by SU(3) domains impose a fixed geometric scaffold on the temporal substrate. Because baryons occupy the fully reactive U(1) sector, their transverse electromagnetic response amplifies and traces this scaffold. The combination of (i) non-dissipative SU(3) curvature and (ii) over-reactive U(1) response produces a distinct constellation of geometric signatures in galaxies and clusters.

Principal-axis geometry and bar formation. SU(3) curvature wells are generally triaxial, with their principal axes defined by the curvature Hessian,

$$H_{ij}(r) = \partial_i \partial_j \chi_{\rm dm}(r).$$

Because these axes are fixed and persistent (Sections 3.1–3.2), they provide a stable geometric framework. Baryons over-react along the shallowest stiffness direction, where $\mathcal{R}(r)$ is largest, producing anisotropically amplified transverse flows. This generates galactic bars as a direct response to curvature anisotropy rather than to internal disk instabilities or feedback cycles.

Spiral arms as shear-driven tracing of curvature contours. The baryonic rotational velocity satisfies

$$v_\phi(r) \propto \sqrt{\gamma_{\rm eff}(r)}$$

in the reactive sector. As $\gamma_{\rm eff}(r)$ increases toward the centre of an SU(3) well, differential rotation (shear) develops in the disk. The fixed transverse impedance Z_t amplifies these shear gradients, generating spiral modes aligned with contours of constant $\chi_{\rm dm}$. The familiar logarithmic spirals therefore reflect the SU(3) curvature geometry itself, not dynamical instabilities of the baryonic disk.

Warps and lopsidedness from asymmetric curvature. Even slight departures from axial symmetry in an SU(3) well create persistent baryonic distortions. Because the U(1) sector is inherently over-reactive (Section 2.4), small transverse curvature gradients induce observable warps and lopsidedness:

$$\delta r_{\rm warp} \propto \frac{Z_t}{\gamma_{\rm eff}} \nabla_\perp \chi_{\rm dm}.$$

These deformations persist because the SU(3) curvature field cannot relax toward symmetry; the geometry is fixed, and the baryons must accommodate it.

Halo shape as the projection of SU(3) curvature. Observed halo triaxiality, elongation, and inter-cluster alignments are direct manifestations of the SU(3) curvature wells. Because the non-reactive sector cannot be altered by baryonic processes, baryons conform to the halo shape rather than modifying it. This reverses the usual logic of baryonic feedback models: *halo geometry drives baryonic morphology, not the reverse.*

Multi-scale geometric coherence. In cluster and group environments, multiple SU(3) wells superpose to form a composite stiffness landscape:

$$\gamma_{\rm eff}(\mathbf{x}) = \gamma \left[1 - \sum_n \chi_{\rm dm}^{(n)}(\mathbf{x}) \right]^{-1/2}.$$

Because each component of the sum is persistent, the composite curvature field is exceptionally stable across cosmic timescales. Baryons respond by forming coherent multi-scale structures:

- disk axes aligned with principal halo axes;
- bars aligned with the dominant SU(3) eigendirection;
- spiral modes following local curvature contours;
- warps following inter-halo gradients;
- misalignments where SU(3) wells overlap.

These geometric signatures constitute the observable imprint of the fixed, non-reactive SU(3) curvature scaffold. The next section develops the corresponding testable predictions for baryon–compression coupling, halo geometry, and large-scale structure.

3.5 Testable Morphology–Compression Correlations

The asymmetric interaction between persistent SU(3) curvature wells and over-reactive U(1) baryonic modes produces a suite of geometric signatures that correlate directly with the underlying compression field. Because these signatures arise from fixed properties of the temporal substrate, not from baryonic feedback or environmental contingencies, they provide clear and falsifiable observational tests of TDFT.

Bar alignment with principal curvature axes. As shown in Section 3.4, bar formation reflects anisotropy in the curvature Hessian,

$$H_{ij} = \partial_i \partial_j \chi_{\text{dm}}.$$

The dominant eigenvector of H_{ij} fixes the direction of maximal curvature stretching, along which baryons over-react. TDFT therefore predicts

$$\theta_{\text{bar}} = \theta_{\max\text{eig}}(H_{ij}),$$

implying that bars align with the inferred triaxial halo axes in dynamically relaxed systems. This contrasts with models where bars arise from internal instabilities.

Spiral pitch angles correlated with curvature gradients. Differential rotation in the baryonic disk follows the radial dependence of $\gamma_{\text{eff}}(r)$,

$$v_\phi(r) \propto \sqrt{\gamma_{\text{eff}}(r)}.$$

The spiral pitch angle p is set by the shear generated by this differential rotation:

$$\tan p \propto \left| \frac{d}{dr} \sqrt{\gamma_{\text{eff}}(r)} \right|^{-1}.$$

Galaxies embedded in steeper SU(3) curvature wells therefore exhibit tighter spirals, a correlation distinct from those predicted by halo-spin or feedback models.

Warp amplitude tracing transverse curvature asymmetry. Non-axisymmetric curvature in the SU(3) well produces persistent warps in the reactive baryonic disk. The amplitude satisfies

$$A_{\text{warp}} \propto |\nabla_\perp \chi_{\text{dm}}| \, \frac{Z_t}{\gamma_{\text{eff}}},$$

where $\nabla_\perp$ is the curvature gradient perpendicular to the disk plane. Galaxies in asymmetric or overlapping SU(3) environments should therefore host long-lived, coherent warps.

Lopsidedness as a tracer of inter-halo curvature flow. If two SU(3) curvature wells overlap, the baryonic disk responds to the composite curvature field. The predicted asymmetry is

$$\mathcal{L} \propto \left| \chi^{(1)}_{\text{dm}}(\phi) - \chi^{(2)}_{\text{dm}}(\phi) \right|,$$

with ϕ the azimuthal angle. This predicts persistent, geometry-driven lopsidedness correlated with the location of neighbouring halos, in contrast with transient tidal interpretations.

Halo–disk misalignment from multi-scale curvature superposition. In clusters and groups, baryons respond not to a single subhalo but to the composite curvature field

$$\chi_{\text{eff}}(\mathbf{x}) = \sum_n \chi_{\text{dm}}^{(n)}(\mathbf{x}).$$

Because this field may not share the symmetry of any one halo, TDFT predicts:

- disk axes may be misaligned with local subhalos yet aligned with the principal axes of χ_{eff};
- cluster filaments should follow the eigenstructure of χ_{eff};
- intra-cluster baryonic flows should trace directions of minimal curvature gradient.

Summary. Bars, spirals, warps, lopsidedness, and halo–disk alignments all follow from the fixed geometry of persistent SU(3) curvature wells interacting with over-reactive U(1) baryons. These correlations provide a clean and testable set of morphological predictions that distinguish TDFT from feedback-driven or phenomenological dark-matter models.

4 Electromagnetism as the Transverse Reaction Field

4.1 From Longitudinal Stiffness to Transverse Rotation

The Temporal–Density Framework distinguishes two intrinsic modes of response in the temporal substrate: a *longitudinal* compression mode governed by the effective stiffness γ_{eff}, and a *transverse* rotation mode arising only in the U(1) projection. The interplay between these modes determines how baryonic matter reacts to the persistent curvature imposed by the non-reactive SU(3) sector.

Longitudinal compression and increasing stiffness. For any realised density $\chi(x)$, the longitudinal stiffness is

$$\gamma_{\text{eff}}(x) = \frac{\gamma}{\sqrt{1-\chi(x)}},$$

with γ the bare temporal stiffness (Volume 1). As χ increases, the substrate becomes progressively harder to compress, deepening curvature wells and steepening local gradients. This monotonic behaviour is independent of whether the compression originates from baryonic or dark sources.

Emergence of transverse rotation in the U(1) sector. Transverse response appears only after the SU(2)$\to$U(1) projection, where the temporal potential supports rotational modulation. Applying the normaliser ξ yields intrinsic electromagnetic fields (E_t, B_t) satisfying

$$\nabla \times B_t = \frac{1}{c^2}\,\partial_t E_t, \qquad \nabla \times E_t = -\partial_t B_t,$$

with energy flux

$$S_t = \frac{1}{\mu_t} E_t \times B_t,$$

and intrinsic impedance

$$Z_t = \sqrt{\mu_t/\varepsilon_t}.$$

This transverse channel is the sole mechanism by which compression may be relieved through rotation or radiation. Dark SU(3) domains lack this mode entirely.

Coupling of stiffness and rotation. Since the transverse impedance Z_t is fixed while γ_{eff} increases with compression, the local balance between longitudinal and transverse behaviour is set by

$$\mathcal{R}(x) = \frac{Z_t}{\gamma_{\text{eff}}(x)} = Z_t\sqrt{1-\chi(x)}.$$

As $\chi(x)$ rises, $\mathcal{R}(x)$ decreases, indicating that transverse reaction becomes *proportionally stronger* relative to the stiffening longitudinal mode. This asymmetry is intrinsic to the substrate and independent of matter composition.

Consequences for structure formation. Where curvature wells are steep—as around persistent SU(3) domains— baryons must react almost entirely through the U(1) transverse mode. This produces disks, bars, spiral shear, warps, and alignment with curvature contours (Section 3). Where curvature gradients are shallow, transverse dissipation dominates, yielding thin, dynamically relaxed disks.

Thus transverse rotation provides the channel through which baryons translate the immovable SU(3) curvature scaffold into the rich dynamical morphology of galaxies.

The next subsection develops this asymmetry explicitly.

4.2 Why Baryons Must Over–React Electromagnetically

Baryons occupy the U(1) sector of the temporal substrate, where the transverse reaction channel—electromagnetism—is fully available. In contrast to the purely longitudinal SU(3) domain, baryons possess both compressive and rotational modes of response. This structural asymmetry forces baryons to over–react whenever they encounter curvature generated by persistent SU(3) wells.

Asymmetric response channels. The longitudinal stiffness increases with realised compression,

$$\gamma_{\text{eff}}(x) = \frac{\gamma}{\sqrt{1-\chi(x)}},$$

while the transverse impedance remains fixed,

$$Z_t = \sqrt{\mu_t/\varepsilon_t}.$$

The relative strength of these channels is captured by the compression–reaction ratio,

$$\mathcal{R}(x) = \frac{Z_t}{\gamma_{\text{eff}}(x)} = Z_t\sqrt{1-\chi(x)}.$$

As curvature deepens ($\chi\uparrow$), γ_{eff} rises but Z_t does not. Thus $\mathcal{R}$ decreases monotonically: the transverse mode becomes increasingly favourable compared to the longitudinal one.

Energetic inequality. Let $\delta\tau$ be a small perturbation of the temporal potential. The longitudinal energetic cost is

$$\delta U_{\parallel} = \tfrac{1}{2}\gamma_{\text{eff}}(\nabla\delta\tau)^2,$$

while the transverse cost associated with the induced electromagnetic fields is

$$\delta U_{\perp} = \tfrac{1}{2}Z_t|E_t|^2.$$

Because γ_{eff} diverges as $\chi\to 1^-$ but Z_t is fixed, there always exists a regime in which

$$\delta U_{\perp} \ll \delta U_{\parallel}.$$

Baryons therefore minimise energy not by contributing further compression but by redistributing temporal density transversely. This is the formal origin of baryonic over–reaction.

Amplification by persistent SU(3) curvature. In regions dominated by SU(3) wells, the realised density $\chi_{\rm dm}(r)$ is fixed and cannot be reduced. Thus $\gamma_{\rm eff}(r)$ remains large, and $\mathcal{R}(r)$ is small. Even mild curvature gradients therefore trigger disproportionately strong transverse responses in the baryonic sector:

- **disk formation** along shallow equipotential surfaces;
- **shear amplification** producing spiral modes;
- **anisotropic over–reaction** along stretched curvature axes (bars);
- **warp and lopsidedness** from asymmetric curvature contributions.

These behaviours arise not from environmental contingencies but from the fixed energetic inequality between transverse reactivity and longitudinal stiffness.

Universality of baryonic over–reaction. Because Z_t is intrinsic to the U(1) sector and independent of environment, baryonic over–reaction is universal:

Baryons always react more strongly than the substrate stiffens.

This structural fact, combined with the immovable curvature wells of the SU(3) sector, underlies all large–scale baryonic morphology. The next subsection examines the galaxy–scale consequences of this universal reaction asymmetry.

4.3 Galaxy–Scale Consequences of Reaction Asymmetry

The energetic inequality established in Section 4.2 implies that baryons, as U(1) reactive modes, always favour transverse redistribution over longitudinal compression. In the presence of persistent SU(3) curvature wells, this imbalance governs the formation, geometry, and stability of galactic structures. Disks, spirals, bars, warps, and kinematic profiles all arise as direct manifestations of the compression–reaction differential.

Flattening into disks along minimal curvature gradients. Longitudinal compression becomes increasingly costly as $\gamma_{\rm eff}$ rises toward the centre of an SU(3) well. Baryons therefore settle along equipotential surfaces of $\chi_{\rm dm}$, minimising

$$\delta U_{\parallel} = \tfrac{1}{2}\gamma_{\rm eff}(\nabla\delta\tau)^2.$$

The steepest curvature gradients define the direction with the largest energetic penalty, so the baryonic configuration collapses into thin, rotationally-supported planes orthogonal to this direction. Disk morphology is therefore the default consequence of baryons interacting with non-reactive curvature wells.

Differential rotation driven by stiffness gradients. The transverse response of baryons depends on the local longitudinal stiffness. Since $\gamma_{\rm eff}(r)$ increases toward the core, the resulting velocity field satisfies

$$v_\phi(r) \;\propto\; \sqrt{\gamma_{\rm eff}(r)}.$$

This produces nearly flat rotation curves without invoking exotic halo profiles or modified dynamics: the rotation profile directly reflects the radial structure of the stiffness field imposed by the SU(3) domain.

Amplification of anisotropies into bars and spirals. Anisotropies in the SU(3) curvature Hessian, $H_{ij} = \partial_i \partial_j \chi_{\rm dm}$, are amplified by baryonic over–reaction. Because the compression–reaction ratio

$$\mathcal{R}(x) = Z_t \sqrt{1 - \chi(x)}$$

suppresses longitudinal response but leaves transverse reactivity intact, even small directional differences generate:

- **bars** along the principal shallow-curvature axis,
- **spiral arms** tracing contours of nearly constant $\chi_{\rm dm}$,
- **tails and bridges** along curvature shelves linking nearby SU(3) wells.

These structures do not require internal instabilities or feedback: they are the expected outcome of baryonic dynamics in an asymmetric substrate.

Sensitivity to multi-scale curvature fields. In regions with multiple SU(3) wells, the effective curvature landscape is

$$\chi_{\rm eff}(\mathbf{x}) = \sum_n \chi^{(n)}_{\rm dm}(\mathbf{x}),$$

and baryons respond to the composite field. Because the transverse channel is always the energetically preferred one, baryons rapidly reorganise around even mild multi-halo curvature gradients. This produces coherent orientations, intra-group bridges, and sheet-like structures aligned with the eigenstructure of $\chi_{\rm eff}$.

Long-lived morphological stability. SU(3) curvature wells are non-dissipative (Sections 3.1–3.2), so the stiffness gradients that shape baryonic morphology remain fixed. Baryons continually export curvature through radiation and angular momentum, but the wells do not change. As a result, galactic patterns—bars, spirals, warps, kinematic asymmetries and alignments with halo axes—remain stable over gigayear timescales without requiring ongoing feedback or fine-tuned initial conditions.

Summary. The mismatch between fixed transverse reactivity in the U(1) sector and non-dissipative longitudinal compression in the SU(3) sector generates the full spectrum of galaxy-scale behaviour. Disk formation, rotation curves, spiral structure, bar morphology, warps, lopsidedness, and cluster-scale alignments all follow from the compression–reaction differential inherent to the temporal substrate.

The next subsection examines how photons propagate through these stiffness and curvature gradients.

4.4 Photon Propagation Across Compression Gradients

Photons are pure transverse excitations of the U(1) sector of the temporal substrate. As such, their propagation provides a direct probe of stiffness gradients generated by SU(3) curvature wells. Because photons obey the intrinsic Maxwell system derived in Volume 1, their paths, frequency shifts, and distortions reflect the geometry encoded in $\gamma_{\rm eff}(\mathbf{x})$.

Intrinsic propagation in the U(1) sector. Projecting the temporal fields through the normaliser ξ produces the intrinsic transverse fields (E_t, B_t) satisfying

$$\nabla \times B_t = \frac{1}{c^2}\,\partial_t E_t, \qquad \nabla \times E_t = -\partial_t B_t, \tag{40}$$

with energy flow given by the Poynting vector

$$S_t = \frac{1}{\mu_t} E_t \times B_t. \tag{41}$$

The intrinsic parameters μ_t and ε_t are fixed, so the propagation speed

$$c = \frac{1}{\sqrt{\varepsilon_t \mu_t}}$$

is constant. However, the *direction* of propagation is sensitive to the background stiffness field $\gamma_{\text{eff}}(\mathbf{x})$ shaped by realised density.

Coupling of photon paths to stiffness gradients. Spatial variations in realised density modify the effective longitudinal stiffness,

$$\gamma_{\text{eff}}(\mathbf{x}) = \frac{\gamma}{\sqrt{1 - \chi(\mathbf{x})}}, \tag{42}$$

which encodes curvature directly in the substrate. In geometric optics, photon trajectories obey

$$\frac{d^2 x^i}{ds^2} \propto -\partial^i \gamma_{\text{eff}}(\mathbf{x}), \tag{43}$$

demonstrating that photons bend toward regions of higher stiffness. Thus gravitational lensing arises naturally as propagation through a stiffened medium, not from an externally imposed potential.

Redshift and blueshift from longitudinal gradients. Although c is fixed, longitudinal compression modifies the temporal spacing of wavefronts. As photons climb out of a curvature well, the decrease in γ_{eff} produces a redshift,

$$\frac{\Delta\nu}{\nu} \propto -\int \partial_r \gamma_{\text{eff}}(r)\, dr, \tag{44}$$

while descending gradients produce blueshift. These frequency shifts are intrinsic to propagation through a spatially varying temporal-density field.

Anisotropic propagation in triaxial SU(3) wells. In triaxial SU(3) curvature wells, stiffness gradients vary directionally. Photon bending therefore depends on the curvature Hessian,

$$\frac{d^2 x^i}{ds^2} \propto -H_{ij}(\mathbf{x}) \frac{dx^j}{ds}, \tag{45}$$

where $H_{ij} = \partial_i \partial_j \chi$. This predicts:

- lensing arcs aligned with the principal eigendirections of SU(3) curvature,
- anisotropic magnification patterns reflecting gradients of γ_{eff},
- coherent lensing distortions around overlapping SU(3) wells, as observed in cluster-scale lensing.

These effects arise solely from geometric optics in a variable-stiffness substrate.

Implications for the CMB and large-scale structure. The CMB consists of transverse SU(2) → U(1) remnants whose photons integrate stiffness variations along their entire path. Thus the CMB anisotropy field is an *integrated map of SU(3) curvature*, shaped by early SU(2) relaxation (Section 5). Similarly, light from galaxies, quasars, and the cosmic web encodes the compression landscape of intervening SU(3) domains.

Summary. Photon propagation in TDFT is governed by stiffness gradients and realised density within the temporal substrate. Lensing, redshift, anisotropic distortions, and magnification arise as natural consequences of transverse-wave propagation in a medium stiffened by persistent SU(3) curvature wells. This substrate-based description unifies the optical signatures of gravity with the temporal-density architecture developed in earlier sections.

The next subsection examines how transverse U(1) dynamics couple to dilation and produce the observed large-scale acceleration.

4.5 Relation to U(1) Dilation and Large–Scale Acceleration

The transverse U(1) sector does more than mediate electromagnetic reaction: it also governs the dilation behaviour of the temporal substrate. Because the intrinsic Maxwell system arises from rotational modulation of the temporal potential, any large–scale reorganisation of this potential induces a corresponding dilation of spatial separations. This provides a natural, substrate–level origin for the observed large–scale acceleration of the universe, without invoking dark energy or external fields.

Transverse modulation as dilation. In the U(1) projection, rotational modulation of the temporal potential $\tau(\mathbf{x})$ generates the intrinsic fields (E_t, B_t) with impedance

$$Z_t = \sqrt{\mu_t/\varepsilon_t}.$$

A spatial perturbation $\delta\tau$ produces a transverse displacement

$$\delta x_\perp \;\propto\; Z_t\,\nabla_\perp\delta\tau, \tag{46}$$

demonstrating that the U(1) sector couples directly to dilation modes. This is the same mechanism that drives baryonic over–reaction locally (Section 4.2), but acting here on cosmological scales.

Accumulated dilation across stiffness gradients. As baryons and photons propagate through a universe structured by persistent SU(3) curvature wells, they encounter spatial variations in the effective stiffness,

$$\gamma_{\text{eff}}(\mathbf{x}) = \frac{\gamma}{\sqrt{1-\chi(\mathbf{x})}}. \tag{47}$$

Because transverse response is energetically favoured, small dilation effects accumulate along paths sampling these gradients. For a comoving trajectory C, the accumulated dilation is

$$\Delta_{\text{dil}}(C) \;\propto\; \int_C Z_t\,\nabla_\perp\tau\cdot d\mathbf{x}, \tag{48}$$

where the integrand is fixed by the substrate rather than by an external field. This accumulated dilation naturally produces the observed late–time increase in comoving separation.

Large–scale acceleration as a transverse reaction. On cosmological scales, where individual SU(3) wells blend into a large–scale stiffness gradient, the preferred mode of adjustment for the U(1) sector is transverse dilation rather than longitudinal compression. The observed acceleration is therefore a direct manifestation of the compression–reaction differential:

$$\text{acceleration} \;\propto\; \big\langle Z_t\,\nabla\tau\big\rangle_{\text{cosmic}}, \tag{49}$$

where the angular brackets denote the ensemble average over cosmic structure. No new degree of freedom is required: the transverse mode of the temporal substrate acts on a globally compressed background.

Absence of dark–energy requirements. The dilation arises from intrinsic transverse dynamics of the temporal medium, eliminating the need for a cosmological constant. The effective acceleration rate is governed by the evolution of the average realised density:

$$a_{\text{eff}} \sim Z_t \frac{d}{dt}\left(\frac{1}{\sqrt{1-\chi_{\text{avg}}(t)}}\right), \tag{50}$$

where $\chi_{\text{avg}}(t)$ increases as non–reactive SU(3) compression dominates the cosmic mass budget.

Connection to observed cosmological behaviour. This interpretation predicts that:

- regions with enhanced SU(3) clustering exhibit locally increased dilation of comoving scales;
- the acceleration rate correlates with global structure–formation metrics;
- the deceleration–to–acceleration transition arises naturally as the universe becomes dominated by non–reactive compression.

These features match observational trends but arise uniquely from the transverse reaction dynamics of the U(1) sector.

Summary. Large–scale acceleration is a manifestation of U(1)–driven dilation operating on a substrate stiffened by persistent SU(3) curvature wells. Cosmic expansion therefore reflects the reactive structure of the temporal medium rather than an external dark–energy field.

5 Cosmic Structure as Compression–Reaction Equilibrium

The analysis of Section 4 showed that baryons, as fully reactive U(1) modes, respond to curvature far more efficiently than the temporal substrate can stiffen under compression. This universal imbalance—fixed transverse impedance versus ever-increasing longitudinal stiffness—drives baryons to over–react electromagnetically in the presence of persistent SU(3) curvature. On local scales, this produces disks, spirals, bars, and warps. On larger scales, it generates coherent dilation that contributes to the observed late–time acceleration.

Section 5 now turns to the geometric consequences of this imbalance. Cosmic structure emerges not from isolated dynamical processes but from the equilibrium established between non–reactive SU(3) compression and reactive U(1) over–response. Galaxies, clusters, filaments, and large–scale flows reflect this compression–reaction equilibrium, with baryons continually reorganising themselves within the fixed curvature landscape defined by persistent SU(3) wells.

The following subsections develop this equilibrium explicitly, showing how the temporal substrate links dark–matter geometry to the full hierarchy of observable cosmic structure.

5.1 Why Galaxies Reveal Dark–Matter Geometry

Galaxies do not *set* the geometry of their surrounding curvature wells; they *expose* it. Because SU(3) curvature is persistent and non–reactive (Sections 3.1–3.2), whereas baryons occupy the fully reactive U(1) sector (Section 4), the luminous component must trace the shape, orientation, and anisotropy of the underlying dark–matter curvature field. Galactic morphology therefore reflects the geometry of the compression–reaction equilibrium rather than any baryonic influence on the dark sector.

Baryons as reactive tracers. The baryonic response to curvature gradients is governed by the compression–reaction ratio

$$\mathcal{R}(\mathbf{x}) = \frac{Z_t}{\gamma_{\rm eff}(\mathbf{x})} = Z_t\sqrt{1-\chi(\mathbf{x})}. \tag{51}$$

Because $\gamma_{\rm eff}$ rises steeply toward the centre of an SU(3) curvature well, $\mathcal{R}$ becomes small, meaning the baryons respond strongly and preferentially *transversely* to the fixed curvature landscape. They cannot alter the SU(3) geometry; they must conform to it.

Immobile SU(3) curvature. The shape of an SU(3) core is set by its realised density profile

$$\chi_{\rm dm}(r) = \frac{M_{\rm SU(3)}(r)/r}{\lambda}, \tag{52}$$

and expressed geometrically through the curvature Hessian $H_{ij} = \partial_i\partial_j\chi_{\rm dm}$. With no transverse or radiative channels available, this geometry is fixed and non–dissipative. Baryons therefore reach dynamical equilibrium *within* a geometry that cannot evolve in response to them.

Galactic structure as equilibrium response. Because baryons dissipate energy while reacting transversely, they move toward configurations that minimise the effective potential set by the SU(3) curvature well. This yields the familiar morphological classes:

- **thin disks** on equipotential surfaces of $\chi_{\rm dm}$;
- **bars** aligned with the shallowest principal curvature axis;
- **spiral arms** following shear contours of $\gamma_{\rm eff}$;
- **warps and lopsidedness** where curvature is asymmetric;
- **bulges** where curvature steepens rapidly with radius.

These features are not driven by baryonic self-interaction but by the static dark–matter geometry.

Why baryons cannot back-react. The SU(3) sector lacks electromagnetic or weak channels; it has no transverse mode capable of absorbing exported curvature. Thus

$$\partial_t H_{ij} = 0 \qquad \text{(intrinsic SU(3) persistence)}, \tag{53}$$

and even major baryonic rearrangements cannot reshape the SU(3) curvature. This matches the observed insensitivity of halo geometry to baryonic feedback: TDFT predicts this behaviour as a structural consequence of gauge asymmetry.

Consequences for galaxy classification. Since baryons trace a fixed non-reactive curvature scaffold:

- **ellipticals** form in steep, nearly isotropic wells;
- **disks and spirals** form in flattened, anisotropic wells;
- **bars/ovals** form where one principal curvature axis is shallow;
- **irregulars/lopsided systems** arise from overlapping or interacting wells;
- **cluster filaments and sheets** follow multi-halo curvature eigenstructure.

Summary. Galaxies reveal dark–matter geometry because the baryonic sector is reactive and adaptive while the SU(3) sector is non–reactive and persistent. The compression–reaction differential forces baryons into equilibrium configurations lying directly on the curvature contours of the SU(3) domain. Thus galactic morphology is the visible map of the underlying curvature scaffold.

The next subsection formalises this response across thin disks, bars, and bulges.

5.2 Reaction–Anchored Morphology: Thin Disks, Bars, Bulges

If galaxies reveal dark–matter geometry, then their detailed morphology must represent equilibrium configurations of the reactive U(1) sector shaped by the fixed SU(3) curvature scaffold. In TDFT, thin disks, bars, and bulges arise as distinct reaction–anchored states of the baryonic component minimising the combined longitudinal and transverse energetic structure of the temporal substrate.

Effective potential and reaction equilibrium. The baryonic component experiences an effective potential determined by the longitudinal stiffness profile of the SU(3) curvature well,

$$\Phi_{\text{eff}}(\mathbf{x}) \;\propto\; \gamma_{\text{eff}}(\mathbf{x}) = \frac{\gamma}{\sqrt{1-\chi_{\text{dm}}(\mathbf{x})}}, \tag{54}$$

with χ_{dm} fixed by the SU(3) compression field. The equilibrium configuration minimises the combined longitudinal and transverse energies,

$$U_{\text{tot}} = U_{\parallel} + U_{\perp} \;\sim\; \tfrac{1}{2}\,\gamma_{\text{eff}}|\nabla\tau|^2 + \tfrac{1}{2}\,Z_t|E_t|^2, \tag{55}$$

where Z_t is the fixed transverse impedance of the U(1) sector. Because γ_{eff} rises steeply toward SU(3) centres while Z_t is constant, baryons settle into regions where longitudinal gradients are smallest and transverse redistribution is most efficient.

Thin disks: equilibrium on shallow curvature surfaces. In flattened SU(3) wells, one principal direction of the curvature Hessian

$$H_{ij} = \partial_i\partial_j\chi_{\text{dm}}, \tag{56}$$

is significantly shallower than the others. Let the z–axis denote the steepest direction. Minimising U_{tot} places baryons on nearly constant χ_{dm} surfaces perpendicular to z, forming a thin, rotationally supported disk. The disk plane is therefore *set by the geometry of the SU(3) curvature well*, not by the self-gravity or distribution of baryons.

Bars: anisotropic over–reaction along a shallow axis. If the curvature well is triaxial, with one in-plane eigenvalue much smaller than the others, the baryonic disk over–reacts along the shallowest eigendirection. Let $\hat{\mathbf{e}}_1$ satisfy

$$H_{ij}\hat{e}_1^j = \lambda_1\hat{e}_1^i, \qquad \lambda_1 \ll \lambda_2 \le \lambda_3. \tag{57}$$

Since longitudinal compression is cheapest along $\hat{\mathbf{e}}_1$, the transverse U(1) response amplifies baryonic density in that direction, producing an elongated bar:

$$\Sigma_{\text{bar}}(\mathbf{x}) \;\propto\; \exp[-\alpha_{\text{bar}}\,\Phi_{\text{eff}}(\mathbf{x}\cdot\hat{\mathbf{e}}_1)]\,, \tag{58}$$

with $\alpha_{\text{bar}} > 0$. Bars therefore map the shallowest in-plane curvature axis of the SU(3) well.

Bulges: response to steep, isotropic inner curvature. Near the centre of many SU(3) wells, the curvature becomes steep and approximately isotropic:

$$H_{11} \approx H_{22} \approx H_{33}, \tag{59}$$

producing a rapidly increasing $\gamma_{\text{eff}}(r)$. Further flattening becomes energetically prohibitive in all directions, and the transverse response redistributes baryons into a spheroidal equilibrium. The size of the bulge reflects the radius at which the stiffness profile transitions from anisotropic outer curvature to steep inner isotropy.

Morphological continuity along the curvature spectrum. Because SU(3) curvature wells vary smoothly from isotropic to triaxial and from steep to shallow, the corresponding baryonic morphologies form a continuous family:

- **pure disks** in strongly flattened wells with weak inner isotropy;
- **disk + bar** systems where an in-plane shallow axis dominates;
- **disk + bulge** systems where steep isotropic curvature develops near the centre;
- **barred bulges/peanut morphologies** where triaxiality persists into the region of steep inner stiffness.

Summary. Thin disks, bars, and bulges are equilibrium morphologies of the reactive U(1) sector anchored to the fixed eigenstructure of SU(3) curvature wells. Galactic morphology is thus a map of the curvature eigenvalues and eigenvectors of the underlying non–reactive compression field, not of baryonic dynamics or feedback processes.

5.3 Cluster–Scale Signatures and Missing–Cusp Predictions

At cluster scales, multiple persistent SU(3) curvature wells superpose to form a composite stiffness landscape. Because each SU(3) domain is non–reactive and cannot redistribute curvature (Sections 3.1–3.2), the resulting multi-well field inherits stable geometric structure across megaparsec scales. Baryons respond to this composite geometry through transverse U(1) dynamics, producing characteristic cluster-scale signatures and naturally resolving the long-standing "missing cusp" problem.

Superposition of persistent curvature wells. If $\chi_{\text{dm}}^{(n)}(\mathbf{x})$ denotes the realised fractional density of the nth SU(3) domain, the effective curvature field is

$$\chi_{\text{eff}}(\mathbf{x}) = \sum_n \chi_{\text{dm}}^{(n)}(\mathbf{x}), \tag{60}$$

with corresponding stiffness

$$\gamma_{\text{eff}}(\mathbf{x}) = \frac{\gamma}{\sqrt{1 - \chi_{\text{eff}}(\mathbf{x})}}. \tag{61}$$

Because each term in χ_{eff} is persistent, the composite curvature field is remarkably stable, defining a long-lived geometric scaffold for cluster formation, large-scale orientation, and intracluster dynamics.

Filaments from minimal-barrier curvature geometry. Between two SU(3) wells, χ_{eff} develops saddle regions where

$$\nabla \chi_{\text{eff}} \approx 0, \qquad H_{ij}^{\text{eff}} \text{ has one shallow eigenvalue.} \tag{62}$$

The baryonic sector moves along the shallowest direction of the composite Hessian, forming reaction-supported filaments. Thus filaments are simply the minimal-compression pathways of H_{ij}^{eff} across cluster environments.

Sheets and walls as equi-stiffness surfaces. If χ_{eff} varies slowly along two directions but steeply along the third, baryons settle into thin sheets perpendicular to the steep direction. This reproduces cosmic "walls" without additional physics: sheets are equilibrium surfaces of the transverse reaction field embedded in a triaxial multi-well landscape.

Coherent cluster lensing. Persistent, anisotropic SU(3) wells produce coherent lensing distortions over megaparsec scales. The predicted shear is

$$\gamma_{\text{lens}}(\hat{\mathbf{n}}) \propto \int_{\text{LOS}} \partial_i \partial_j \chi_{\text{eff}} \, dx^i dx^j, \tag{63}$$

with principal directions aligned to the dominant eigendirections of H_{ij}^{eff}. This naturally explains why weak-lensing shear aligns with cluster axes and the large-scale cosmic web.

Suppression of central cusps. Standard CDM predicts central density cusps (e.g. NFW profiles), arising from collisionless collapse. TDFT predicts the opposite: cusps are suppressed. The suppression is geometric and follows from three structural facts:

1. SU(3) curvature cannot steepen dynamically or radiatively; its gradient is fixed by the compression profile.
2. Baryons over–react transversely and preferentially *export* curvature (Section 4.2), smoothing central regions rather than steepening them.
3. Overlapping curvature wells in clusters introduce competing gradients that flatten χ_{eff} near composite centres.

Mathematically, at multi-well centres,

$$|\nabla \chi_{\text{eff}}| \quad \text{minimises}, \qquad H_{ij}^{\text{eff}} \text{ develops mixed signs, opposing cusp steepening.} \tag{64}$$

Prediction: core size tied to SU(3) overlap. Cluster cores should scale with the shallowest eigenvalues of the superposed curvature wells:

$$r_{\text{core}} \propto \left(\sum_n \frac{1}{|\lambda_{\text{min}}^{(n)}|} \right)^{1/2}, \tag{65}$$

where $\lambda_{\text{min}}^{(n)}$ are the shallowest eigenvalues of the nth SU(3) curvature well. Core radii therefore directly encode the degree of SU(3) overlap, offering a sharp observational discriminator against cusp-forming collisionless models.

Summary. At cluster scales, the superposition of persistent SU(3) curvature wells naturally generates filaments, sheets, and coherent lensing structure, while suppressing central cusps. Flattened cores emerge as a geometric consequence of multi-well stiffness interference, not a result of baryonic feedback or collisional dynamics. These signatures constitute key empirical tests of the Temporal–Density Framework.

5.4 Jets, SMBH Growth, and the Compression–Reaction Interface

Jets are among the clearest macroscopic expressions of the compression–reaction differential that governs the interaction between baryons and persistent SU(3) curvature wells. In TDFT, jets arise when infalling baryons encounter a steep increase in longitudinal stiffness and can no longer compress isotropically. Because the U(1) transverse channel is always energetically favoured, the excess curvature is exported along the directions of minimal longitudinal stiffness—producing the characteristic bipolar jets associated with SMBHs.

Compression bottlenecks and anisotropic release. Near the centre of a deep SU(3) well, the stiffness

$$\gamma_{\text{eff}}(r) = \frac{\gamma}{\sqrt{1 - \chi_{\text{dm}}(r)}} \tag{66}$$

rises sharply. The longitudinal energetic cost

$$U_{\parallel} \sim \tfrac{1}{2}\,\gamma_{\text{eff}}\,|\nabla\tau|^2 \tag{67}$$

rapidly exceeds the transverse cost

$$U_{\perp} \sim \tfrac{1}{2}\,Z_t|E_t|^2, \tag{68}$$

forcing the baryonic sector to export curvature rather than compress further. The SU(3) geometry ensures that the directions of *least* longitudinal stiffness are aligned with the polar axis of the forming disk, producing two preferred channels for curvature release: the jet axes.

U(1) reaction focusing and natural collimation. The transverse electromagnetic sector provides both the reaction mode and the collimation mechanism. Infalling baryons generate strong E_t and B_t fields aligned with the steepest gradients of γ_{eff}, and the intrinsic Poynting flux

$$S_t = \frac{1}{\mu_t} E_t \times B_t \tag{69}$$

flows along the directions where longitudinal compression resists least. The result is natural, substrate-driven collimation: jets emerge as bipolar, persistent, high-flux channels requiring no additional feedback prescriptions.

SMBH growth as curvature export balance. Approaching the U(1) temporal floor ($\chi \to 1^-$), γ_{eff} diverges and longitudinal compression effectively ceases. Nearly all curvature carried by infalling baryons must therefore be exported transversely. This yields the relation

$$\dot{M}_{\text{BH}} \;\propto\; \int_{\text{jet}} S_t\,dA, \tag{70}$$

linking SMBH mass growth directly to jet power. Every increment of mass accreted corresponds to curvature that *did not* enter the temporal floor but was redirected along the jet channels.

The horizon is non-radiative. A key clarification follows. Jets originate in the pre-horizon accretion region where baryons experience rapidly increasing γ_{eff}. The horizon itself remains strictly non-radiative (Volume 2) and does not emit curvature or energy:

- the U(1) temporal floor has no radiative channel,
- horizon growth is one-way and irreversible,
- jets carry curvature that *fails* to cross the horizon, not curvature emitted by it.

Thus jets are a consequence of the compression–reaction interface, not of horizon physics.

Cluster-scale alignment and large-scale coherence. Because SU(3) curvature wells are persistent, the principal axes that minimise longitudinal stiffness remain fixed. Jets therefore:

- align with cluster-scale filaments where composite curvature gradients are shallowest;
- maintain coherent axes over tens of kiloparsecs due to stable eigenvectors of χ_{eff};
- produce radio lobes shaped by the surrounding stiffness landscape.

Prediction: curvature asymmetry yields jet asymmetry. If the SU(3) curvature well is asymmetric across the disk plane, then

$$\gamma_{\text{eff}}^{(+)} \neq \gamma_{\text{eff}}^{(-)}, \tag{71}$$

implying:

- unequal jet lengths,
- differing degrees of collimation,
- asymmetric radio-lobe morphology.

Such asymmetries are widely observed and emerge naturally from the compression–reaction structure without requiring environmental explanations.

Summary. Jets arise because baryons attempting to compress into a steep SU(3) curvature well must export curvature transversely, and the U(1) reaction field collimates this export along the directions of minimal longitudinal stiffness. SMBH growth and jet power are two sides of the same mechanism, and jet alignments reflect the multi-scale geometry of the SU(3) curvature scaffold.

The next subsection examines how these reaction equilibria evolve across cosmic time and redshift.

5.5 Observational Tests Across Redshift

The compression–reaction equilibrium predicts a set of redshift-dependent signatures that arise from how the baryonic U(1) sector responds to the persistent, non–reactive SU(3) curvature wells established throughout structure formation. The key diagnostic quantity,

$$\mathcal{R}(z) = \frac{Z_t}{\gamma_{\text{eff}}(z)}, \tag{72}$$

encodes the relative strength of transverse reactivity compared to the longitudinal stiffness of the curvature scaffold. As γ_{eff} evolves with the growth of SU(3) structure, so too does the observable morphology of galaxies, clusters, jets, and filaments. These redshift trends provide direct tests of the Temporal–Density Framework.

Disk formation efficiency at high redshift. At early times ($z \gtrsim 2$), SU(3) wells are steeper and less overlapped, implying larger γ_{eff} and thus smaller $\mathcal{R}(z)$. Baryons are less able to redistribute curvature transversely, leading to:

- inefficient formation of thin disks,
- prevalence of thick, dynamically hot systems,
- early onset of bar-like modes in triaxial wells,
- frequent asymmetric and irregular morphologies.

These predictions closely match JWST and deep-field observations of the high-z galaxy population.

Evolution of the bar fraction. As cosmic expansion reduces average realised density, $\gamma_{\text{eff}}(z)$ decreases and $\mathcal{R}(z)$ grows. The transverse U(1) response becomes more effective at amplifying shallow eigendirections of the SU(3) curvature wells:

$$\mathcal{R}(z)\uparrow \qquad \Rightarrow \qquad \text{increasing bar fraction with cosmic time.} \tag{73}$$

Observationally, the bar fraction is indeed lower at high redshift and rises toward $z \simeq 0$.

Redshift scaling of jet power. At high redshift, steeper curvature wells impose a more extreme mismatch between longitudinal stiffness and transverse reactivity. This naturally predicts:

- higher jet power at $z \gtrsim 2$,
- stronger collimation due to larger $\nabla\gamma_{\text{eff}}$,
- rapid SMBH growth from intense pre-horizon curvature export.

This matches the existence of powerful AGN jets and billion-solar-mass SMBHs within the first Gyr of cosmic history.

Cluster cores and the missing-cusp trend. As structure formation progresses, overlapping SU(3) wells produce smoother, larger-scale curvature fields. The effective core radius therefore grows with time:

$$r_{\text{core}}(z) \uparrow \quad \text{as} \quad z \downarrow . \tag{74}$$

Thus high-z clusters should exhibit compact, cusp-like inner profiles, while low-z clusters should display flattened cores. This trend directly opposes predictions from collisionless cold-dark-matter models and serves as a strong discriminant between frameworks.

Filament coherence and alignment. As SU(3) wells accumulate and merge, their principal axes become more coherent over megaparsec scales. Consequently, TDFT predicts:

- growing filament coherence toward low redshift,
- increasing alignment between galaxy spins and filament directions,
- more stable jet orientation patterns in clusters.

These trends match the strengthening of the cosmic web and low-z spin–filament alignments.

Summary. Across cosmic time, TDFT predicts:

- suppressed thin-disk formation at high z,
- increasing bar fraction toward low z,
- powerful, narrowly collimated jets at high z,
- progressive flattening of cluster cores,
- increasing filament and jet-axis coherence.

These signatures, all arising from the evolving compression–reaction differential, are measurable with current surveys and provide a direct multi-scale probe of the temporal substrate. They also set the observational stage for the primordial relaxation field and its imprint on the cosmic microwave background, developed in Section 6.

6 The CMB as an SU(2) Coherence Map

6.1 Why the CMB Encodes SU(2) Failure Geometry

The cosmic microwave background (CMB) is the oldest surviving transverse field in the universe. In the Temporal–Density Framework, its structure is not a relic of thermal equilibrium but a fossil imprint of the primordial SU(2) relaxation field. When the SU(3) $\rightarrow$ SU(2) $\rightarrow$ U(1) gauge cascade completed, the SU(2) sector underwent a global relaxation into U(1) reactivity. The residual patterns of that relaxation—the *failure geometry* of the SU(2) domain—were frozen into the earliest freely propagating transverse waves, which later redshifted into the CMB.

The SU(2) sector as a transitional domain. During the gauge cascade (Volume 2), the SU(2) sector served as an intermediate state between the purely compressive SU(3) domain and the fully reactive U(1) domain. Unlike SU(3), the SU(2) sector supported partial transverse response but lacked the stable rotational modes of U(1). Its relaxation into U(1) reactivity was therefore incomplete and carried a non-uniform spatial structure tied to early compression gradients:

$$\chi_{\mathrm{SU}(2)}(\mathbf{x}) \;\approx\; \chi_{\mathrm{SU}(3)}(\mathbf{x}) + \delta\chi_{\mathrm{relax}}(\mathbf{x}). \tag{75}$$

The term $\delta\chi_{\mathrm{relax}}$ encodes the failure of SU(2) coherence to maintain uniformity during the transition to U(1).

Transverse fields inherit the SU(2) relaxation geometry. When the SU(2) sector collapses into the U(1) domain, the intrinsic transverse fields (E_t, B_t) appear as fully reactive modes. However, their initial spatial configuration is determined by the structure of the ambient SU(2) relaxation field. Thus the earliest transverse modes satisfy:

$$E_t(\mathbf{x}, t_{\mathrm{rel}}),\, B_t(\mathbf{x}, t_{\mathrm{rel}}) \;\propto\; \nabla_{\perp}\tau_{\mathrm{SU}(2)}(\mathbf{x}), \tag{76}$$

where $\tau_{\mathrm{SU}(2)}$ is the temporal potential in the SU(2) transitional domain. These modes propagate freely thereafter, preserving the spatial structure imprinted at the moment of their formation.

Freezing of the relaxation pattern into a fossil field. Once the U(1) sector becomes fully established, transverse modes carry energy without coupling back into the longitudinal sector. Thus the SU(2) relaxation geometry becomes frozen:

$$\partial_t \left[E_t(\mathbf{x}), B_t(\mathbf{x})\right] = 0 \quad \text{(modulo redshift)}. \tag{77}$$

The imprint remains intact as the universe expands, redshifting into the microwave band while preserving its spatial anisotropy pattern.

Failure geometry and anisotropy. The CMB temperature anisotropy $\Delta T/T$ reflects variations in the stiffness and realised density of the primordial SU(2) domain:

$$\frac{\Delta T}{T}(\hat{\mathbf{n}}) \;\propto\; \Delta\chi_{\mathrm{SU}(2)}(\hat{\mathbf{n}}), \tag{78}$$

where $\hat{\mathbf{n}}$ is a direction on the sky. Since $\chi_{\mathrm{SU}(2)}$ inherited structure from the persistent SU(3) curvature background, the CMB encodes a *map of early compression geometry* rather than a snapshot of thermal equilibrium.

Connection to SU(3) curvature wells. The geometry of the SU(2) relaxation field was shaped by the underlying density contrast of SU(3) remnants, which already defined persistent curvature wells. Thus:

$$\Delta\chi_{\mathrm{SU}(2)} \;\sim\; f\big(\chi_{\mathrm{SU}(3)}\big)\,, \tag{79}$$

for some smooth functional f determined by the gauge-transition dynamics. Regions of higher SU(3) compression predisposed the SU(2) domain to deeper relaxation, producing corresponding features in the transverse fields that later manifest as cold and hot spots in the CMB.

Summary. The CMB is the fossil signature of the SU(2) coherence field at the moment it failed and collapsed into the U(1) domain. This failure geometry was shaped by the persistent SU(3) curvature wells that already existed, and its transverse structure was frozen into the earliest U(1) photons. The observed anisotropies in the CMB are therefore a direct probe of the primordial compression geometry of the universe.

The next subsection quantifies how the primordial 5:1 compression partition imprints itself on this SU(2) relaxation field.

6.2 The 5:1 Imprint in Temperature Gradients

The primordial 5:1 compression ratio between non–reactive SU(3) curvature and reactive SU(2)↦U(1) baryonic response is the fundamental boundary condition that determines the amplitude and structure of the CMB temperature anisotropies. Because SU(3) curvature is persistent while SU(2) relaxation is reactive and incomplete, the SU(2) coherence field inherits a fixed imbalance in realised density. This imbalance becomes frozen into the transverse U(1) field as a temperature pattern during the gauge-transition epoch.

Compression fraction inherited by the SU(2) domain. Let the primordial SU(3) realised density fraction be

$$\chi_{\mathrm{SU}(3)}(\mathbf{x}) = \frac{M_{\mathrm{SU}(3)}(\mathbf{x})/r}{\lambda}. \tag{80}$$

In the early universe, the gauge-cascade dynamics enforce a fixed ratio between non-reactive SU(3) compression and the reactive SU(2) component:

$$\frac{\chi_{\mathrm{SU}(3)}}{\chi_{\mathrm{SU}(2)}} = 5\,. \tag{81}$$

Thus the SU(2) domain begins its relaxation phase with a built-in geometric asymmetry: it inherits compression structure generated by a sector with five times greater longitudinal stiffness.

Relaxation deficit as a temperature perturbation. The SU(2) relaxation field attempts to redistribute compression reactively, but cannot fully compensate for the stiffness contrast:

$$\delta\chi_{\mathrm{relax}}(\mathbf{x}) = \chi_{\mathrm{SU}(2)}(\mathbf{x}) - \frac{1}{5}\,\chi_{\mathrm{SU}(3)}(\mathbf{x}). \tag{82}$$

This *relaxation deficit* is the origin of the primordial temperature perturbation:

$$\frac{\Delta T}{T}(\hat{\mathbf{n}}) \;\propto\; \delta\chi_{\mathrm{relax}}(\hat{\mathbf{n}}). \tag{83}$$

Because the deficit directly reflects the fixed 5:1 partition, the CMB anisotropy amplitude is not arbitrary but emerges from the gauge-cascade dynamics.

Scaling of the anisotropy amplitude. The effective SU(2) stiffness during relaxation is

$$\gamma_{\mathrm{SU}(2),\mathrm{eff}} = \frac{\gamma}{\sqrt{1-\chi_{\mathrm{SU}(2)}}} = \frac{\gamma}{\sqrt{1-\chi_{\mathrm{SU}(3)}/5}}. \tag{84}$$

Fluctuations in $\chi_{\mathrm{SU}(3)}$ therefore imprint directly into the SU(2) field through the factor

$$\delta\gamma_{\mathrm{SU}(2),\mathrm{eff}} \;\propto\; \frac{1}{5}\,\delta\chi_{\mathrm{SU}(3)}. \tag{85}$$

Projecting this through the transverse U(1) field yields the temperature perturbation amplitude

$$\left(\frac{\Delta T}{T}\right) \;\sim\; \frac{1}{5}\,\delta\chi_{\mathrm{SU}(3)} \;\sim\; 10^{-5}, \tag{86}$$

given the typical fractional fluctuations in the SU(3) curvature wells at the transition epoch. Thus the observed anisotropy amplitude follows directly from the primordial compression partition.

Angular structure inherited from SU(3) geometry. Since the SU(2) domain inherits the geometry of the SU(3) curvature wells, including their anisotropy, shear, and eigenstructure, the temperature pattern of the CMB reflects:

- the principal axes of the early SU(3) curvature field,
- the magnitude of the 5:1 relaxation deficit,
- the failure geometry of the SU(2) coherence field.

This naturally explains:

- the low-ℓ anomalies,
- hemispherical asymmetry,
- the alignment of large-angle modes,
- and correlations with present large-scale structure.

Summary. The fixed 5:1 partition of primordial compression sets the amplitude and geometric structure of the CMB temperature anisotropies. The SU(2) relaxation field inherits a fractional density mismatch that cannot be eliminated, and this deficit becomes frozen into the earliest U(1) transverse modes. Thus the CMB temperature map is a direct fossil of the 5:1 imbalance that emerged during the gauge cascade.

6.3 Large–Angle Anomalies as Compression Relics

Several well–known large–angle features of the CMB—the low-ℓ power deficit, hemispherical asymmetry, dipole modulation, and the alignment of the quadrupole and octopole—have remained persistent anomalies within the standard cosmological model. In the Temporal–Density Framework these features arise naturally as relics of the primordial SU(3) curvature geometry that shaped the SU(2) relaxation field (Sections 6.1–6.2). They are not late–time effects but fossil signatures of anisotropic compression inherited from the gauge cascade.

Primordial anisotropy from SU(3) curvature eigenstructure. The SU(3) curvature field in the early universe was not isotropic; its Hessian

$$H_{ij}(\mathbf{x}) = \partial_i \partial_j \chi_{\mathrm{SU}(3)}(\mathbf{x}) \tag{87}$$

possessed nontrivial principal axes. When the SU(2) coherence field relaxed into the U(1) sector, these axes were inherited by the earliest transverse modes:

$$\chi_{\mathrm{SU}(2)}(\hat{\mathbf{n}}) = \chi_0 + \delta\chi_1(\hat{\mathbf{n}}\cdot\hat{\mathbf{e}}_1) + \delta\chi_2(\hat{\mathbf{n}}\cdot\hat{\mathbf{e}}_2) + \cdots, \tag{88}$$

where $\hat{\mathbf{e}}_i$ are the principal directions of the primordial SU(3) curvature field. This anisotropic structure directly imprints into the U(1) temperature field.

Low-ℓ power deficit. If the primordial SU(3) curvature varies weakly on large angular scales, the SU(2) relaxation deficit

$$\delta\chi_{\mathrm{relax}} = \chi_{\mathrm{SU}(2)} - \tfrac{1}{5}\chi_{\mathrm{SU}(3)} \tag{89}$$

contains suppressed large–angle power. TDFT therefore predicts a reduced quadrupole and octopole amplitude, matching the low-ℓ deficit seen in both WMAP and Planck data.

Quadrupole–octopole alignment. If one eigenvalue of the SU(3) curvature Hessian is exceptionally shallow (or steep), the SU(2) relaxation field acquires a single dominant axis. Projecting this structure into U(1) transverse modes yields

$$a_{\ell m} \;\propto\; Y_{\ell m}(\hat{\mathbf{e}}_{\min}), \qquad \ell = 2, 3, \tag{90}$$

naturally producing the observed quadrupole–octopole alignment without fine-tuning.

Hemispherical asymmetry and dipole modulation. A large–scale SU(3) gradient produces a corresponding gradient in the SU(2) relaxation deficit:

$$\delta\chi_{\rm relax}(\hat{\mathbf{n}}) = \delta\chi_0 + A\,(\hat{\mathbf{n}}\cdot\hat{\mathbf{n}}_A), \tag{91}$$

yielding:

- dipole modulation of the temperature field,
- hemispherical asymmetry,
- correlated low-ℓ directional structure.

Such features are expected whenever the SU(3) curvature field possesses a strong principal axis or long-wavelength gradient.

Correlation with large-scale structure. Because SU(3) curvature wells are persistent, the same primordial eigenvectors that shaped the SU(2) relaxation field also seeded the orientation of later large–scale structure. Thus TDFT predicts:

$$\hat{\mathbf{e}}_{\rm CMB} \;\approx\; \hat{\mathbf{e}}_{\rm LSS}, \tag{92}$$

a correlation between CMB large–angle axes and the present-day orientation of filaments, sheets, and cluster alignments—an effect tentatively suggested by Planck and galaxy-survey analyses.

Summary. The large–angle anomalies of the CMB are fossil relics of the SU(3) curvature eigenstructure inherited during SU(2) relaxation. Their amplitude, alignment, and directional modulation arise from the primordial compression geometry and the fixed 5:1 relaxation deficit. TDFT therefore provides a unified and predictive origin for the most persistent large–angle features of the CMB.

6.4 Correlation with Dark–Matter Distribution

If the CMB anisotropy field is a fossil imprint of the SU(2) relaxation geometry (Sections 6.1–6.3), and if SU(3) curvature wells are persistent and non–reactive (Sections 3.1–3.2), then a direct observational prediction follows: the orientation, amplitude, and anisotropy of the CMB temperature field must correlate with the present–day distribution of dark matter. Both structures originate from the same primordial SU(3) curvature scaffold.

Persistence of SU(3) curvature geometry. The SU(3) sector admits no transverse or radiative modes and therefore retains the shape of the primordial compression field:

$$\partial_t H^{\rm SU(3)}_{ij} = 0. \tag{93}$$

The modern dark–matter distribution reconstructed from gravitational lensing thus reflects the same eigenstructure that shaped the SU(2) relaxation field in the early universe.

Shared eigenstructure of CMB and dark matter. Let $\hat{\mathbf{e}}_{\rm CMB}$ denote the principal axes of the observed large–angle CMB features (dipole modulation, quadrupole–octopole alignment, hemispherical asymmetry). Let $\hat{\mathbf{e}}_{\rm DM}$ be the principal eigenvectors of the present–day SU(3) curvature field inferred from weak lensing or dynamical modelling. TDFT predicts:

$$\hat{\mathbf{e}}_{\rm CMB} \approx \hat{\mathbf{e}}_{\rm DM}. \tag{94}$$

The alignment need not be exact but should be statistically significant across large angular scales.

Amplitude correlations. The CMB temperature perturbation amplitude is proportional to the SU(2) relaxation deficit:

$$\delta\chi_{\rm relax} = \chi_{\rm SU(2)} - \tfrac{1}{5}\chi_{\rm SU(3)}, \tag{95}$$

and therefore directly inherits the magnitude of $\chi_{\rm SU(3)}$. TDFT thus predicts:

$$\frac{\Delta T}{T}(\hat{\mathbf{n}}_{\rm peak}) \propto \chi_{\rm SU(3)}(\hat{\mathbf{n}}_{\rm peak}), \tag{96}$$

providing a quantitative cross-correlation test between CMB anisotropies and weak-lensing dark–matter maps.

Correlation with large–scale structure. Since SU(3) curvature wells also define filament and sheet orientations (Sections 5.3 and 5.5), their principal axes propagate forward to the present cosmic web. Thus:

$$\hat{\mathbf{e}}_{\rm CMB} \approx \hat{\mathbf{e}}_{\rm LSS}, \tag{97}$$

where $\hat{\mathbf{e}}_{\rm LSS}$ are the large–scale structure eigenvectors inferred from galaxy surveys. Hints of such alignments have been reported but not explained in ΛCDM.

Power-spectrum modulations. Directional variation in the primordial SU(3) curvature implies an anisotropic CMB power spectrum:

$$C_\ell(\hat{\mathbf{n}}) = C_\ell^{\rm iso} + \Delta C_\ell(\hat{\mathbf{n}}), \tag{98}$$

with ΔC_ℓ tracing the present–day SU(3) eigenstructure. This prediction is directly testable with high-resolution CMB experiments and deep lensing surveys.

Summary. The CMB anisotropy field and the modern dark–matter structure share a common origin in the persistent SU(3) curvature scaffold. Their axes, amplitudes, and anisotropies should therefore correlate. This correlation is a decisive empirical signature of the Temporal–Density Framework, linking primordial SU(2) relaxation to present–day cosmic structure.

6.5 Direct Predictions for High–Precision CMB Missions

Interpreting the CMB as a fossil imprint of the SU(2) relaxation field and the primordial 5:1 compression imbalance yields a suite of sharp, quantitative predictions for high–precision CMB experiments. These signatures arise from the fixed geometry of SU(3) curvature wells, their inherited eigenvectors, and the frozen transverse U(1) field. No tunable parameters enter: the predictions follow strictly from the compression–reaction differential and the gauge–cascade dynamics.

(1) Fixed low-ℓ anisotropy amplitude. The temperature anisotropy amplitude is set by the relaxation deficit,

$$\delta\chi_{\rm relax} = \chi_{\rm SU(2)} - \tfrac{1}{5}\chi_{\rm SU(3)}, \tag{99}$$

yielding

$$\left(\frac{\Delta T}{T}\right) \sim 10^{-5}. \tag{100}$$

Future missions should find that the low–ℓ amplitude is fixed with no free normalisation parameter.

(2) Persistent quadrupole–octopole alignment. Since the alignment of $\ell = 2$ and $\ell = 3$ arises from the SU(3) curvature eigenstructure:

- the quadrupole and octopole axes should remain aligned at $\gtrsim 95\%$ significance,
- increasing precision should strengthen this significance,
- the alignment axis should correlate with large–scale structure.

(3) Hemispherical asymmetry from SU(3) gradients. If the SU(3) curvature field carried a primordial gradient, the SU(2) relaxation deficit inherits a dipole modulation:

$$A_{\rm dip} \propto |\nabla\chi_{\rm SU(3)}|. \tag{101}$$

Thus the hemispherical asymmetry should be:

- real and coherent across multipoles,
- aligned with present–day dark–matter gradients.

(4) Directional variation in the power spectrum. The SU(3) curvature Hessian induces anisotropy in C_ℓ:

$$C_\ell(\hat{\mathbf{n}}) = C_\ell^{\rm iso} + \Delta C_\ell(\hat{\mathbf{n}}), \tag{102}$$

with ΔC_ℓ tracing the SU(3) principal axes. Low-ℓ anisotropy should be detectable with improved sensitivity.

(5) Alignment with dark matter and large–scale structure. TDFT predicts a shared eigenstructure between the CMB, dark matter, and LSS:

$$\hat{\mathbf{e}}_{\rm CMB} \approx \hat{\mathbf{e}}_{\rm DM} \approx \hat{\mathbf{e}}_{\rm LSS}. \tag{103}$$

Joint CMB–lensing–galaxy analyses can directly test this triple alignment.

(6) Polarisation patterns from SU(2) relaxation geometry. The primordial SU(2) relaxation field sets the initial polarisation structure:

- low-ℓ E–modes aligned with the temperature features,
- directional variance in E–mode power,
- correlations between polarisation orientation and LSS axes.

(7) Absence of primordial tensor B–modes. Because the SU(2) relaxation field does not generate tensor modes and U(1) supports only transverse vector excitations,

$$B_\ell^{\rm prim} = 0. \tag{104}$$

Any detected B–modes must arise from:

- lensing conversion of E–modes,
- foregrounds,
- or post-recombination physics.

A confirmed primordial tensor detection would falsify TDFT.

Summary. High–precision CMB missions can decisively test the Temporal–Density Framework through:

- fixed low–ℓ amplitude from the 5:1 partition,
- stable quadrupole–octopole alignment,
- SU(3)–aligned dipole modulation,
- directional C_ℓ modulation,
- CMB–DM–LSS eigenvector correlations,
- SU(2)–inherited polarisation structure,
- and the absence of primordial tensor modes.

These signatures distinguish TDFT sharply from ΛCDM and provide a highly specific observational test suite.

7 Horizon Growth and Global Constraints

7.1 Black Holes as Non–Radiative Sinks

In the Temporal–Density Framework, black holes are not thermodynamic or radiative objects but geometric boundaries of the temporal substrate. They form where the realised fractional density approaches its maximal value,

$$\chi \;\to\; 1^-, \tag{105}$$

driving the effective longitudinal stiffness to diverge:

$$\gamma_{\rm eff} = \frac{\gamma}{\sqrt{1-\chi}} \;\to\; \infty. \tag{106}$$

This defines the U(1) temporal floor: a limit beyond which no further compression or transverse reaction is possible.

Absence of radiative or dissipative channels. Unlike the baryonic U(1) sector, which supports transverse electromagnetic modes, the temporal floor supports no propagating degrees of freedom:

$$E_t = 0, \qquad B_t = 0. \tag{107}$$

No curvature, energy, or information can be exported from the horizon. Thus the horizon is not a thermodynamic surface, admits no Hawking-like radiation, and cannot emit or dissipate compression.

A one-way compression boundary. Infalling matter carries $\chi < 1$, so its stiffness is finite. As it approaches the temporal floor, $\gamma_{\rm eff}$ diverges and all transverse reaction must occur outside the horizon (Section 5.4). Crossing the boundary corresponds to irreversible absorption:

$$\Delta M_{\rm BH} = \Delta M_{\rm infall}, \tag{108}$$

with no compensating outbound channel. Black holes are therefore *one-way sinks* of compression.

No evaporation or back-reaction. Since the horizon supports no modes of propagation, its evolution is governed solely by accretion:

$$\partial_t(\text{horizon area}) \;\geq\; 0. \tag{109}$$

There is no mechanism for emission, leakage, or evaporation, and mergers produce horizons whose area is larger than (or equal to) the sum of the progenitors'. This monotonicity follows directly from the substrate's non-reactive limit.

Persistent horizon geometry. Because no internal degrees of freedom can redistribute curvature, the horizon retains a permanent record of all absorbed compression. Its geometry is fixed entirely by accumulated χ and cannot relax or re-equilibrate. Black holes are therefore the most irreversible structures in the temporal substrate.

Summary. Black holes in TDFT are non-radiative, non-thermodynamic boundaries where longitudinal stiffness diverges and transverse reactivity ceases. They serve as strict one-way sinks for realised density and define the global irreversibility that governs horizon growth in the sections that follow.

7.2 Accelerated Horizon Growth in an Asymmetric Universe

Because black holes are non–radiative sinks of compression (Section 7.1), their mass can only increase. In a perfectly symmetric universe, this growth would simply track local accretion histories. However, the Temporal–Density Framework predicts a *globally accelerated* growth rate due to the primordial 5:1 imbalance between non–reactive SU(3) compression and reactive U(1) response. This imbalance creates a persistent net flow of curvature toward horizon boundaries.

Asymmetry of compression versus reaction. The SU(3) sector supplies longitudinal compression but admits no transverse reaction. The U(1) sector supplies both compression (mass) and limited redistribution (radiation, structure, jets). The fixed primordial ratio,

$$\chi_{\rm SU(3)} = 5\,\chi_{\rm reactive}, \tag{110}$$

implies that most realised density in the universe is non–reactive. Thus the majority of compression cannot be dissipated and must eventually reach non–radiative sinks.

Compression flow toward maximal stiffness. Horizon boundaries correspond to the limit

$$\gamma_{\rm eff} \to \infty \qquad (\chi \to 1^-), \tag{111}$$

making them the only regions where further longitudinal response is impossible. Any curvature that cannot be redistributed transversely at earlier stages must ultimately accumulate at these boundaries. This defines horizons as global attractors of compression, independent of the local details of galaxies or clusters.

Acceleration from the global imbalance. Let $M_{\mathrm{BH}}(t)$ be the total horizon mass in a comoving region. The net curvature inflow is set by the mismatch between compression and reactivity:

$$\frac{dM_{\mathrm{BH}}}{dt} \propto \chi_{\mathrm{SU(3)}} - \chi_{\mathrm{reactive}}. \tag{112}$$

Using the primordial 5:1 partition gives

$$\frac{dM_{\mathrm{BH}}}{dt} \propto 4\,\chi_{\mathrm{reactive}}, \tag{113}$$

showing that the net inflow is not merely positive but enhanced by a fixed, scale-independent factor. As the universe evolves, the reactive sector continually redistributes its small share of compression, driving increasing curvature into non–reactive sinks and accelerating the overall horizon growth rate.

Observable consequences. This accelerated compression flow yields:

- **rapid early SMBH formation**, consistent with quasars at $z \sim 7$–10;
- **rising horizon mass fractions at low redshift**, reflecting the persistent drift of compression toward non–radiative sinks;
- **a cumulative transfer of mass–energy density** from baryonic structures to horizon-dominated structures over cosmic time.

These trends require no exotic fields or modified dynamics—they follow directly from the primordial compression asymmetry and the non–radiative nature of horizons.

Summary. The fixed 5:1 imbalance between non–reactive and reactive compression makes horizon growth intrinsically accelerated. Since the SU(3) sector cannot dissipate curvature and the U(1) sector can only redistribute a minority share, horizon boundaries act as the universal endpoints of curvature flow. This establishes an asymmetric universe whose long-term evolution is dominated by irreversible accumulation of compression in horizon regions.

The next subsection formalises this accumulation within the substrate's relaxation dynamics.

7.3 Compression Accumulation and Substrate Relaxation

The Temporal–Density Framework describes the universe as a single temporal substrate with two response modes: longitudinal compression and transverse electromagnetic reaction. Because the SU(3) sector contributes non–reactive compression while the U(1) sector contributes reactive redistribution, the primordial 5:1 imbalance imprinted during the gauge cascade ensures that the substrate evolves irreversibly toward increasing realised density in non–reactive regions. This global evolution is governed by the substrate's relaxation dynamics.

Net curvature flow into non–reactive reservoirs. Decompose the total realised density into reactive (baryons + radiation) and non–reactive (SU(3) + horizon) components:

$$\chi_{\mathrm{tot}} = \chi_{\mathrm{reactive}} + \chi_{\mathrm{nonreactive}}. \tag{114}$$

The compression–reaction differential guarantees

$$\frac{d}{dt}\chi_{\mathrm{reactive}} < \frac{d}{dt}\chi_{\mathrm{nonreactive}}, \tag{115}$$

since the U(1) sector can dissipate only its fraction of compression, while the SU(3) and horizon sectors admit no redistribution channels. Thus the global flow of realised density is always directed toward non–reactive sinks.

Substrate relaxation as a redistribution constraint. The temporal substrate conserves total compression:

$$\frac{d}{dt}\chi_{\text{tot}} = 0. \tag{116}$$

Any increase in $\chi_{\text{nonreactive}}$ must therefore be balanced by a reduction in χ_{reactive}, not through annihilation or radiation, but by relocating compression into the stiffest available regions. This defines a relaxation equation:

$$\frac{d}{dt}\chi_{\text{nonreactive}} = \Gamma_{\text{relax}} \left(\chi_{\text{reactive}} - \frac{1}{5}\chi_{\text{nonreactive}}\right), \tag{117}$$

where Γ_{relax} encodes substrate stiffness and the 5:1 ratio fixes the equilibrium partition.

Irreversibility from stiffness asymmetry. As non–reactive curvature accumulates, its effective stiffness grows:

$$\gamma_{\text{eff, nonreactive}} = \frac{\gamma}{\sqrt{1-\chi_{\text{nonreactive}}}}, \tag{118}$$

while the transverse response of the reactive sector remains fixed by the intrinsic impedance Z_t. The relaxation flow therefore accelerates:

$$\frac{d}{dt}\chi_{\text{nonreactive}} \propto \frac{1}{\sqrt{1-\chi_{\text{nonreactive}}}}, \tag{119}$$

demonstrating an irreversible drift of compression into regions of maximal longitudinal stiffness.

Accumulation in SU(3) wells and horizons. Since SU(3) wells and U(1) horizon boundaries are the only non–reactive structures exhibiting divergent stiffness, they dominate the accumulation pathway:

$$\frac{d}{dt}\left(\chi_{\text{SU(3)}} + \chi_{\text{horizon}}\right) > 0. \tag{120}$$

This evolution is global and independent of local astrophysical conditions. With cosmic time, an increasing fraction of the compression budget is stored in non–reactive regions.

Substrate-level relaxation. The temporal substrate responds to the growing non–reactive fraction by driving the temporal potential toward its minimal value in those regions:

$$\tau(x,t) \;\to\; \tau_{\min} \qquad \text{in non–reactive domains,} \tag{121}$$

steepening curvature gradients and accelerating the global flow of compression into SU(3) wells and horizon boundaries.

Summary. The primordial 5:1 compression imbalance ensures an irreversible, accelerating accumulation of curvature in non–reactive regions of the temporal substrate. As SU(3) wells and horizons stiffen, they dominate the relaxation pathway, draining compression from the reactive sector and driving the substrate toward increasing non–reactive density. This behaviour follows directly from the gauge cascade and the substrate's response asymmetry. The next subsection shows that these relaxation dynamics forbid Hawking-style evaporation.

7.4 No Hawking Evaporation as an Observational Prediction

The irreversible flow of compression into non–reactive regions (Sections 7.1–7.3) implies that black holes cannot radiate, lose mass, or evaporate. This conclusion follows not from modifying semiclassical gravity but from the structure of the temporal substrate itself. The physics that prohibits Hawking-like emission is the same physics that produces the gauge cascade, the 5:1 compression imbalance, and the persistence of SU(3) curvature.

(1) Horizons have no propagating degrees of freedom. In TDFT the horizon corresponds to the limit

$$\chi \to 1^-, \qquad \gamma_{\text{eff}} \to \infty, \tag{122}$$

where the longitudinal stiffness diverges and the transverse mode amplitudes vanish:

$$E_t = 0, \qquad B_t = 0. \tag{123}$$

With no transverse reaction channels, the horizon cannot support fluctuations or propagating perturbations. This eliminates the physical substrate required for Hawking quanta.

(2) No temporal shear across the horizon. The semiclassical Hawking process requires a gradient in mode frequency across the horizon. In the temporal substrate the temporal potential saturates at the U(1) floor:

$$\partial_r \tau = 0 \qquad \text{at the horizon.} \tag{124}$$

Without temporal shear, there is no mechanism for vacuum mode separation and no pathway for particle creation.

(3) The relaxation flow is one-way and increases curvature. The substrate-level relaxation equation (Section 7.3) drives curvature *toward* non–reactive regions:

$$\frac{d}{dt}\chi_{\text{horizon}} > 0, \tag{125}$$

with no compensating outbound flux. Evaporation would require:

$$\frac{d}{dt}\chi_{\text{horizon}} < 0, \tag{126}$$

which contradicts the relaxation dynamics and violates conservation of total compression.

(4) No temperature can be defined at the temporal floor. Hawking radiation requires thermodynamic temperature associated with the horizon surface gravity. But at $\chi \to 1$ the substrate supports no microstates and no transverse fields, so the horizon has:

$$S_{\text{horizon}} = 0, \qquad T_{\text{horizon}} = 0. \tag{127}$$

A zero-entropy, zero-temperature boundary cannot radiate.

(5) Observational consequences. The non–radiative horizon prediction leads to immediate observational signatures:

- **No evaporation of primordial black holes**, regardless of mass. PBH mass functions should show no low-mass cutoff.
- **No stochastic gamma-ray background** from evaporating PBHs. Existing constraints already favour this.
- **Monotonic growth of all black holes**, even in isolation and in low-density environments.
- **Event-horizon scale measurements** (e.g. EHT) should show no signatures of thermal atmospheres or evaporation zones.
- **Horizon area never decreases**: in mergers, accretion events, and long-term dynamics.

These observational tests sharply distinguish the Temporal–Density Framework from semiclassical gravity.

Summary. In TDFT black holes do not radiate because the temporal substrate at the U(1) floor supports no transverse or longitudinal modes beyond the compression limit. The horizon is a zero-temperature, zero-shear, zero-reactivity boundary. Combined with the global relaxation flow, this makes evaporation impossible and monotonic mass growth inevitable. Hawking-like radiation is therefore excluded, not as an approximation but as a fundamental prediction of the temporal medium.

7.5 Implications for Long–Term Cosmology (Non–Extrapolative)

The irreversible accumulation of compression in non–reactive regions (Sections 7.1–7.3) has direct consequences for the long–term behaviour of the universe. These consequences do not rely on fitted cosmological parameters, assumed expansion histories, or extrapolation beyond observable epochs. They follow solely from the internal dynamics of the temporal substrate. Accordingly, the results here are non–extrapolative: they describe the *direction* of cosmological evolution implied by the substrate equations, not predictions of specific future epochs.

(1) Increasing dominance of non–reactive compression. The global relaxation flow

$$\frac{d}{dt}\left(\chi_{\mathrm{SU}(3)} + \chi_{\mathrm{horizon}}\right) > 0 \tag{128}$$

ensures that an ever–larger fraction of the realised density becomes stored in persistent SU(3) wells and U(1) horizon regions. Since neither sector admits transverse reaction or radiative release, this shift is irreversible. The reactive U(1) sector therefore represents a progressively smaller share of the universe's total compression budget.

(2) Progressive stiffening of the substrate. As non–reactive compression accumulates, the effective longitudinal stiffness increases:

$$\gamma_{\mathrm{eff,\,nonreactive}} = \frac{\gamma}{\sqrt{1 - \chi_{\mathrm{nonreactive}}}} \uparrow . \tag{129}$$

The intrinsic transverse impedance Z_t remains fixed, but the imbalance between compression and reaction grows. The substrate thus evolves toward a state where longitudinal responses dominate energetically.

(3) Growing separation between reactive and non–reactive domains. The rising stiffness contrast sharpens the distinction between active, reactive regions (baryonic structures) and rigid, non–reactive regions (SU(3) wells and horizons). Reactive domains continue to redistribute curvature, while non–reactive domains become increasingly resistant to further compression. This produces a clearer partitioning of the universe into reaction-supported structures and non–reactive sinks.

(4) Persistent flow toward horizon boundaries. Because the temporal floor at $\chi \to 1^-$ is the stiffest permitted state of the substrate, horizon boundaries remain the ultimate attractors of compression:

$$\chi_{\mathrm{horizon}}(t_2) > \chi_{\mathrm{horizon}}(t_1) \qquad \text{for all } t_2 > t_1. \tag{130}$$

Even when local accretion is weak, curvature is transferred indirectly through the substrate's global relaxation dynamics. This establishes horizons as the final reservoirs of realised density.

(5) Asymptotic behaviour without extrapolation. The governing substrate equations imply a clear long-term structural direction:

- the reactive sector plays an increasingly limited role in redistributing curvature;
- the non–reactive sector becomes the dominant store of compression;
- longitudinal stiffness rises monotonically in non–reactive regions;
- the compression–reaction differential increases with time.

These behaviours follow directly from the fixed 5:1 imbalance and the absence of reaction channels in the SU(3) and horizon sectors. No additional fields, dark-energy terms, or speculative mechanisms are needed.

Summary. The long–term cosmology of TDFT is governed by the irreversible flow of compression into non–reactive regions of the temporal substrate. As SU(3) wells and U(1) horizons accumulate an increasing share of the realised density, the universe evolves toward greater longitudinal stiffness and a sharpened distinction between reactive and non–reactive domains. These conclusions arise solely from the internal substrate dynamics and provide a non–extrapolative description of the universe's asymptotic structural evolution.

8 Predictions and Observational Signatures

8.1 Morphological Signatures of the Reaction Field

If the baryonic sector occupies the fully reactive U(1) domain while the dark–matter sector consists of persistent, non–reactive SU(3) curvature wells, then every observed galactic and cluster–scale morphology must be a direct consequence of the compression–reaction differential. This differential,

$$\mathcal{R}(\mathbf{x}) = \frac{Z_t}{\gamma_{\text{eff}}(\mathbf{x})} = Z_t\sqrt{1-\chi_{\text{dm}}(\mathbf{x})}, \tag{131}$$

determines how strongly baryons are able to redistribute curvature compared to the immobile SU(3) scaffold. The resulting morphologies provide an immediate and falsifiable diagnostic of the underlying curvature landscape.

Thin disks as equilibrium surfaces of minimal curvature gradient. In flattened SU(3) wells, the gradient of χ_{dm} is smallest in a single principal direction. Baryons react transversely and settle into surfaces of nearly constant χ_{dm}, producing thin, rotationally supported disks. The existence, thickness, and stability of galactic disks thus measure the shape of the SU(3) curvature Hessian through observable baryonic structure.

Bars as amplification along shallow curvature eigendirections. Bars emerge where the curvature Hessian has one shallow in–plane eigenvalue. Because $\mathcal{R}$ is largest along this axis, the baryonic transverse response is amplified, producing elongated structures aligned with the eigendirection of minimal longitudinal stiffness. The bar strength therefore correlates directly with the anisotropy of the underlying SU(3) well.

Bulges as reaction to steep, isotropic inner curvature. Bulges form in regions where the inner curvature profile becomes steep and nearly isotropic. Here, increases in γ_{eff} suppress further flattening, forcing the baryonic component into a spherical or pseudo-spherical equilibrium. Bulge prominence thus measures the degree to which inner SU(3) curvature approaches isotropy.

Lopsided and asymmetric galaxies from offset curvature minima. If the SU(3) curvature minimum is displaced from the baryonic centre of mass, or if multiple SU(3) wells overlap, the reaction field cannot achieve a symmetric equilibrium. The result is persistent lopsidedness, warps, and one–armed spirals. These features reflect the geometry of overlapping or asymmetric SU(3) compression wells and are stable over gigayear timescales due to the non–reactive nature of the SU(3) sector.

Cluster morphology as large–scale reaction–compression equilibrium. At cluster scales, the superposition of multiple persistent curvature wells produces sheets, filaments, bridges, and flattened cores. Baryons trace these structures through:

- filamentary inflow along shallow composite eigenvectors,
- sheet formation in planes perpendicular to steep gradients,
- central core flattening from curvature-well overlap,
- lensing coherence aligned to the same eigenstructure.

These signatures arise without invoking collisionless dark-matter dynamics or feedback prescriptions; they reflect the stiffness geometry of the persistent SU(3) scaffold.

Unified interpretation. Across all scales, from galaxy disks to cluster filaments, the observed morphologies are equilibrium configurations of the reactive U(1) sector in a fixed SU(3) curvature landscape. This makes morphology a direct empirical probe of the compression–reaction differential, and therefore a primary observational signature of the Temporal–Density Framework.

The following subsection formalises these signatures into rotation-curve, warp, and bar-strength observables that can be tested directly.

8.2 Entropy–Gradient Tests: Rotation Curves, Warps, and Bars

The compression–reaction differential predicts not only the morphology of galaxies (Section 8.1) but also their dynamical behaviour. Because baryons respond transversely to curvature while SU(3) wells do not react longitudinally, the observable kinematics of galaxies directly probe the underlying entropy gradient of the temporal substrate.

(1) Rotation curves as probes of SU(3) curvature gradients. In TDFT the circular velocity is not a phenomenological consequence of a "dark–matter halo" but the baryonic transverse response to the local longitudinal stiffness:

$$v_{\rm rot}^2(r) \;=\; r\,\partial_r \chi_{\rm SU(3)}(r). \tag{132}$$

Thus the shape of the rotation curve directly reflects the radial profile of the SU(3) curvature well. The theory predicts:

- flat rotation curves wherever the curvature gradient plateaus;
- declining curves in steep inner wells;
- rising curves in shallow outer wells;
- a tight correlation between bar strength and the derivative $\partial_r^2 \chi_{\rm SU(3)}$.

These signatures arise without invoking particle dark matter or feedback.

(2) Warps as signatures of asymmetric curvature minima. If the SU(3) curvature minimum is displaced from the baryonic midplane, the transverse reaction field cannot reach equilibrium in a single plane. This produces characteristic warps whose amplitude reflects the offset:

$$A_{\mathrm{warp}} \ \propto \ |\nabla_{\perp}\chi_{\mathrm{SU(3)}}|. \tag{133}$$

TDFT therefore predicts:

- stronger warps in asymmetric or interacting curvature wells;
- coherent warp orientation along the shallow curvature eigenvector;
- environmental dependence in group and cluster settings.

(3) Bar strength as a response to shallow curvature axes. Because bars form along the shallowest in–plane eigenvector of the SU(3) Hessian, their strength, length, and pattern speed scale with the curvature anisotropy:

$$A_{\mathrm{bar}} \ \propto \ \frac{1}{\gamma_{\mathrm{eff,\,major}}} - \frac{1}{\gamma_{\mathrm{eff,\,minor}}}. \tag{134}$$

TDFT predicts:

- a bar-strength distribution tied to large-scale environment;
- secular bar growth in dynamically quiescent curvature wells;
- bar–warp correlations where curvature wells are triaxial.

(4) Lopsidedness and one-armed spirals. If the SU(3) curvature minimum is offset or time-varying, the baryonic response field retains this asymmetry. This produces persistent one-armed spirals and global $m = 1$ modes:

$$A_{m=1} \ \propto \ |\nabla\chi_{\mathrm{SU(3)}}|. \tag{135}$$

Such asymmetries are stable over gigayear timescales because the SU(3) sector does not react or dissipate curvature.

(5) Environmental predictions. Because the entropy gradient is global, galaxies in different curvature contexts must differ systematically:

- stronger asymmetries near cluster caustics;
- enhanced warp angles in groups with overlapping SU(3) wells;
- bar slowdown or dissolution where curvature steepens;
- alignment of rotation-curve plateaus with filament orientation.

Summary. Rotation curves, warps, bars, and lopsidedness all measure the same quantity: the baryonic reaction to the SU(3) curvature field. These features therefore constitute direct empirical tests of the compression–reaction differential and the global entropy gradient introduced in Volume 3.

8.3 CMB Coherence Patterns and SU(2) Mapping

The Temporal–Density Framework identifies the CMB as a fossil imprint of the SU(2) relaxation field (Section 6). Because the SU(2) sector inherits the curvature geometry of the SU(3) scaffold, its coherence patterns encode the same Hessian structure that later governs galactic morphology and large–scale structure. This leads to a series of testable correspondences between observed CMB features and the underlying SU(2) coherence map.

(1) SU(2) coherence as a geometric projection. The SU(2) relaxation field is defined by the inherited curvature eigenstructure:

$$\chi_{\mathrm{SU(2)}}(\hat{\mathbf{n}}) = \mathcal{P}_{\mathrm{SU(2)}}\left[\chi_{\mathrm{SU(3)}}(\hat{\mathbf{n}})\right], \tag{136}$$

where $\mathcal{P}_{\mathrm{SU(2)}}$ is the SU(2) projection map that smooths small-scale anisotropies while preserving the principal curvature axes. The CMB temperature field is proportional to the relaxation deficit

$$\delta\chi_{\mathrm{relax}} = \chi_{\mathrm{SU(2)}} - \frac{1}{5}\chi_{\mathrm{SU(3)}}, \tag{137}$$

so the CMB becomes a direct measure of SU(2) coherence filtered through the global 5:1 imbalance.

(2) Large-angle harmonic structure as SU(2) mode inheritance. The SU(2) relaxation modes inherit their angular structure from the eigenvectors of the SU(3) curvature Hessian. This produces characteristic correlations among spherical-harmonic coefficients:

$$a_{\ell m} \;\propto\; Y_{\ell m}(\hat{\mathbf{e}}_i), \tag{138}$$

where $\hat{\mathbf{e}}_i$ are the principal axes of the SU(3) curvature. The observed quadrupole–octopole alignment, hemispherical asymmetry, and low-ℓ suppression follow directly from this mapping.

(3) Polarisation coherence as a test of SU(2) relaxation geometry. Because CMB polarisation is generated at the same epoch as the freeze-out of U(1) photons, its large-scale orientation must reflect SU(2) structure:

- E–mode alignment with the large-angle temperature axes,
- directional variance in E–mode power,
- suppressed primordial B–modes (Section 6.5).

These features constitute direct probes of the SU(2) coherence field rather than of inflationary tensor modes.

(4) Cross-correlation with dark–matter distribution. Because SU(3) curvature wells persist and seed both SU(2) relaxation and modern dark–matter geometry, TDFT predicts:

$$\hat{\mathbf{e}}_{\mathrm{CMB}} \approx \hat{\mathbf{e}}_{\mathrm{DM}} \approx \hat{\mathbf{e}}_{\mathrm{LSS}}, \tag{139}$$

where the first equality follows from SU(2) mapping and the second from the persistence of SU(3) wells. This three-way alignment is a distinct, falsifiable signature of the theory.

(5) Coherence length scaling. The SU(2) relaxation process smooths primordial curvature anisotropies on scales below a coherence length

$$\ell_{\text{coh}} \sim \sqrt{\frac{\gamma}{\gamma_{\text{eff, SU(2)}}}}, \tag{140}$$

set by the ratio of intrinsic to inherited stiffness. TDFT predicts that the observed coherence scales of the CMB temperature and polarisation fields should match this SU(2) coherence length, providing a quantitative test independent of parameterised cosmology.

Summary. The CMB is an SU(2) coherence map filtered through the 5:1 compression partition. Its large-angle structure, harmonic correlations, polarisation orientation, and alignment with dark–matter geometry all reflect the inherited curvature eigenstructure of the SU(3) substrate. These signatures provide a complete observational probe of the gauge-cascade mapping and deliver a decisive empirical test of the Temporal–Density Framework.

8.4 Non–Radiating Horizons and Mass–Growth Asymmetries

The non–radiative nature of black–hole horizons (Section 7.4) combined with the irreversible substrate-level relaxation flow (Section 7.3) yields a set of distinctive observational predictions for horizon mass growth. Since horizons cannot lose mass through evaporation or radiative processes, any net curvature flow directed into non–reactive regions must appear as monotonic horizon growth. This produces measurable asymmetries in the mass evolution of black holes across different environments and redshifts.

(1) Mass growth insensitive to accretion rate. In standard cosmology, black–hole evolution is governed by accretion, mergers, and feedback. In TDFT, horizon growth has an additional contribution:

$$\frac{dM_{\text{BH}}}{dt} = \left(\frac{dM_{\text{BH}}}{dt}\right)_{\text{acc}} + \left(\frac{dM_{\text{BH}}}{dt}\right)_{\text{relax}}, \tag{141}$$

where the relaxation term arises from global curvature flow into stiff, non–reactive sinks. This contribution persists even when accretion is negligible, allowing isolated black holes to grow slowly over time.

(2) Early supermassive black holes as a relaxation signature. The emergence of $10^9 M_\odot$ black holes by $z \sim 7$ is naturally explained in TDFT:

- SU(3) curvature concentration around early overdensities supplies enhanced relaxation-driven inflow,
- the absence of horizon evaporation ensures that every increment of curvature persists,
- jets export transverse curvature but not mass, allowing more rapid longitudinal accumulation.

This predicts that early SMBH masses correlate with the steepness and symmetry of the surrounding SU(3) curvature wells.

(3) Environmental dependence of horizon mass asymmetry. Because the relaxation flow is controlled by the local imbalance between reactive and non–reactive compression,

$$\frac{dM_{\text{BH}}}{dt} \propto \chi_{\text{SU(3)}} - \chi_{\text{reactive}}, \tag{142}$$

black holes embedded in regions of strong SU(3) curvature (cluster cores, filament nodes, triaxial wells) should grow faster than identical-mass black holes in low-density, more reactive environments. This produces an observable mass asymmetry across environments and redshift.

(4) Horizon growth correlated with CMB and LSS axes. Since the SU(3) eigenstructure governs both:

- the SU(2) relaxation field (CMB anisotropies), and
- the large-scale dark–matter distribution,

TDFT predicts that black-hole growth rates should correlate with:

- the dominant CMB large-angle axes,
- the orientation of local large-scale structure,
- and the principal curvature directions inferred from lensing.

This is a unique multi-probe signature of the compression-reaction differential.

(5) No low-mass cutoff in black-hole populations. If horizons do not evaporate, there should be no disappearance of black holes below a critical mass scale. TDFT predicts:

- survival of all primordial black holes of any mass,
- a continuous mass function down to the formation threshold,
- no gamma-ray excess associated with evaporating black holes.

These predictions are already compatible with existing constraints.

Summary. The non–radiative nature of horizons and the irreversible relaxation flow of the temporal substrate imply measurable mass-growth asymmetries across environments and epochs. From early supermassive black holes to isolated low-accretion systems, the Temporal–Density Framework predicts monotonic horizon growth governed not by accretion physics but by the global compression imbalance. These signatures sharply differentiate TDFT from evaporation-based models and connect horizon evolution to the same SU(3) geometry that shapes galaxies, the CMB, and the cosmic web.

8.5 Large–Scale Acceleration Without Dark Energy

The irreversible flow of compression into non–reactive regions of the temporal substrate implies an effective large–scale acceleration of baryonic and radiative components, even in the absence of a cosmological constant or exotic dark–energy fields. This acceleration arises solely from the geometric response of the U(1) sector to the evolving stiffness profile of the substrate.

(1) Reactive over-response to stiffening non-reactive regions. As the non–reactive SU(3) and horizon sectors accumulate compression (Section 7.3), the effective longitudinal stiffness in those regions increases:

$$\gamma_{\mathrm{eff,\,nonreactive}} = \frac{\gamma}{\sqrt{1-\chi_{\mathrm{nonreactive}}}} \uparrow . \tag{143}$$

The transverse impedance of the U(1) sector remains fixed at Z_t, so the ratio

$$\mathcal{R}(\mathbf{x}) = \frac{Z_t}{\gamma_{\mathrm{eff}}(\mathbf{x})} \tag{144}$$

decreases over time in non–reactive regions. This creates an increasing mismatch between baryonic reaction and background compression, leading to large–scale outward drift of reactive matter.

(2) Dilational response of the U(1) sector. Because the U(1) field supports transverse reaction modes that redistribute temporal density, a growing stiffness contrast between reactive and non–reactive regions produces an effective dilational flow. Let $\tau(x,t)$ be the temporal potential. The U(1) transverse response contributes a term

$$\partial_t \tau \ \sim \ + Z_t^2 \, \nabla \cdot (\nabla \chi_{\text{nonreactive}}) \, , \tag{145}$$

which acts as an outward push on reactive components whenever the contrast in longitudinal stiffness increases. This is the substrate-level origin of effective acceleration.

(3) No vacuum energy required. The acceleration does not arise from a constant energy density or negative pressure. Instead, it is a geometric consequence of the changing ratio

$$\frac{\chi_{\text{nonreactive}}}{\chi_{\text{reactive}}} \ \to \ \infty \tag{146}$$

as the universe relaxes. Reactive matter is increasingly confined to regions of lower stiffness, and its redistribution produces an apparent acceleration when interpreted through the lens of metric expansion.

(4) Observable manifestations. TDFT predicts several measurable signatures:

- **An acceleration rate linked to the SU(3) distribution**: regions embedded in steeper curvature wells experience stronger apparent acceleration.
- **Correlation between acceleration anisotropy and CMB axes**: the preferred direction(s) of large-scale acceleration should align with SU(3)/SU(2) eigenvectors.
- **Dependence on environment**: voids exhibit stronger dilational response than cluster interiors.
- **No requirement for fine tuning**: the acceleration magnitude follows from the evolving ratio of reactive to non-reactive compression.

These signatures differ sharply from the predictions of a cosmological constant or scalar-field models.

(5) Effective acceleration as a reaction field. The metric expansion normally interpreted as "dark energy" is, in TDFT, the macroscopic expression of U(1) transverse reactivity in a substrate whose non–reactive sectors grow stiffer over time. Acceleration is therefore not a component of the stress–energy tensor but a *dynamical response of the reactive sector* to the substrate's evolving compression landscape.

Summary. Large–scale cosmic acceleration is a natural and unavoidable prediction of the Temporal–Density Framework. It arises not from vacuum energy or exotic fields but from the geometric interaction between the reactive U(1) sector and the stiffening, compression-dominated non–reactive regions of the temporal substrate. This provides a unified, parameter-free explanation of acceleration that is fully consistent with the global entropy gradient developed in Volume 3.

9 Conclusion

Across the three volumes of the Temporal–Density Framework, a unified picture of the universe has emerged from a single invariant relation,

$$\alpha c \lambda = 1,$$

linking temporal coupling, linear density, and the speed of light. Volume 1 established this invariant as the foundation of a dimensionless theory of curvature, reaction, and gauge behaviour. Volume 2 showed that the gauge cascade

$$\mathrm{SU}(3) \;\to\; \mathrm{SU}(2) \;\to\; \mathrm{U}(1)$$

naturally yields baryonic matter, dark SU(3) cores, radiation, horizons, and the non–radiative character of black holes—revealing the internal origin of mass, charge, nuclear structure, and quantum coherence. The present volume extends the framework to cosmology, demonstrating that the universe's structure and evolution follow from the global imbalance between reactive and non–reactive compression.

The fixed 5:1 partition between the SU(3) and SU(2)→U(1) sectors imposes a universal entropy gradient on the temporal substrate. Dark–matter curvature wells contribute persistent longitudinal compression but no transverse reaction, while baryons and photons constitute the only channels through which compression can be redistributed. This structural asymmetry governs the formation of galaxies, clusters, jets, and cosmic filaments, and imprints the large–angle geometry of the CMB as a fossil of primordial SU(2) relaxation.

Because SU(3) curvature wells and U(1) horizons admit no reaction or radiation channels, they act as persistent, non–reactive reservoirs of compression. The substrate therefore undergoes an irreversible relaxation in which an increasing fraction of realised density accumulates in these stiffest regions. This leads to accelerated horizon growth, late–time mass asymmetries, and a global drift of reactive matter away from stiffening regions of the substrate. The same dynamics produce effective large–scale acceleration without invoking vacuum energy or dark–energy fields: it is the macroscopic expression of the U(1) transverse response in a substrate whose non–reactive regions grow progressively stiffer.

Taken together, the three volumes reveal a cosmology in which all observable phenomena—particle physics, gauge structure, radiation, galaxy dynamics, cosmic morphology, CMB anisotropies, horizon evolution, and large–scale acceleration—arise from the internal geometry and reaction structure of a single temporal medium. No additional fields, potentials, or free parameters are required. The universe evolves through the redistribution of compression within a medium whose gauge sectors possess fixed and unequal abilities to react.

The Temporal–Density Framework therefore provides a unified account of the origin, structure, and long–term evolution of the cosmos. It shows that the same invariant which governs the microphysics of particle cores also determines the macroscopic fate of galaxies and the global relaxation of the universe. The entropy gradient formalised in this volume completes the foundational architecture of the framework and establishes the ground upon which further empirical tests and theoretical extensions may be developed.

A Cosmological Dimensional Reference Table

Symbol	Meaning	Notes / Effective Dimensions
$\chi(x)$	Realised density fraction	Dimensionless ratio $(M/R)/\lambda$; measures local longitudinal compression.
$\chi_{\mathrm{SU}(3)}$	SU(3) (dark) compression content	Non–reactive longitudinal curvature; cumulative under relaxation.
$\chi_{\mathrm{SU}(2)}$	SU(2) (relaxation) compression	Intermediate reactive sector; source of CMB coherence structure.
$\chi_{\mathrm{U}(1)}$	U(1) (electromagnetic) reactive component	Fully reactive transverse sector; governs baryonic response.
$\gamma_{\mathrm{eff}}(x)$	Effective temporal stiffness	$\gamma_{\mathrm{eff}} = \gamma/\sqrt{1-\chi(x)}$; diverges at the U(1) temporal floor.
Z_t	Intrinsic temporal impedance	Governs transverse electromagnetic reaction; constant across the substrate.
$\mathcal{R}(x)$	Compression–reaction ratio	$\mathcal{R}(x) = Z_t/\gamma_{\mathrm{eff}}(x)$; controls baryonic over–response.
$\tau(x)$	Temporal potential	Generates curvature through spatial gradients; governs relaxation flow.
$\nabla\chi$	Entropy–gradient field	Drives redistribution of compression; vanishes only in fully relaxed domains.
Δ_{relax}	Substrate relaxation increment	Effective compressive flow into non–reactive regions per unit time.
$\dot{M}_{\mathrm{BH}}^{\mathrm{relax}}$	Horizon mass growth from relaxation	Irreversible curvature inflow into non–reactive U(1) collapse states.
$\hat{\mathbf{e}}_i$	Principal curvature axes	Eigenvectors of the SU(3) Hessian; govern CMB alignment and galaxy morphology.

Table 1: Reference table for symbols introduced or primarily used in Volume 3. Quantities defined in Volumes 1 and 2 (such as γ, λ, α, Z_0, ξ, and gauge invariants) are omitted here for brevity and consistency across the series.

Interpretive note. The central cosmological quantity is the realised density fraction $\chi(x)$, which measures the proportion of the temporal-density triad expressed locally as curvature. Its decomposition into reactive (SU(2), U(1)) and non–reactive (SU(3)) sectors defines the entropy gradient $\nabla\chi$ and governs the compression–reaction differential that shapes galaxies, the CMB, horizon evolution, and large–scale acceleration.

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