INTERMEDIATE FILTER METRIC Z

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ABSTRACT

In this work I present a new cosmological framework in which spacetime, matter, and causality are not fundamental entities, but rather emergent phenomena arising from the dynamics of an effective scalar field Z that encodes the organization of correlations in the underlying system. The model is constructed around an equilibrium point $Z = 0.5$, which defines a regime of maximum coherence, while deviations $\phi = Z - 0.5$ generate observable physical structure.

The dynamics are formulated using a nonlinear action dependent on the kinetic invariant $X = \nabla\mu Z \nabla\mu Z$ along with the introduction of a logarithmic term of the form $(\zeta R(2ln)R)$, which acts as a dynamic "brake": a cost associated with deviations from equilibrium. This term regulates the growth of invariants in extreme regimes, preventing divergences and replacing singularities with a regime of controlled saturation.

In this framework, gravity emerges not as a fundamental interaction, but as an effective geometric tension induced by the redistribution of correlations. The quantum–classical transition arises as an intrinsic process of decoherence, without the need for an external observer, while cosmological expansion is interpreted as the global evolution of the field's correlation state.

In a unified manner, the model describes gravitational dynamics, structure formation, and cosmological acceleration, and suggests a resolution to the information loss paradox in black holes. Taken together, the theory proposes that geometry, time, and physical dynamics emerge from a single underlying structure, providing a new path toward the unification of general relativity and quantum mechanics.

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Introduction

The contemporary description of nature is based on two remarkably successful theoretical frameworks: general relativity, formulated by Albert Einstein in 1915, which models gravity as a geometric manifestation of spacetime, and quantum mechanics, which describes the dynamics of physical systems in terms of superposition, correlations, and probabilistic evolution. Despite their extraordinary predictive power in their respective domains, the unification of these two theories remains one of the central problems of contemporary theoretical physics. Various contemporary approaches have explored this issue from perspectives such as quantum gravity, holography, and proposals for emergent gravity, where geometry is interpreted as a property derived from more fundamental degrees of freedom (Van Raamsdonk, 2010).

A fundamental difficulty lies in the structural difference between their formulations: while general relativity assumes a pre-existing dynamic geometry, quantum mechanics introduces time as an external parameter. This conceptual tension suggests that unification might not be achieved through a simple combination of both frameworks, but rather through the identification of a more fundamental level at which both geometry and quantum dynamics emerge from a common underlying structure.

This work proposes a theoretical framework in which gravity, dark matter, and dark energy are interpreted as emergent manifestations of the dynamics of an effective scalar field Z , understood as a macroscopic variable that encodes the organization of the correlations of the underlying physical system. In this approach, spacetime, time, and matter are not considered fundamental entities, but rather effective descriptions that emerge in regimes where the field dynamics allow for the formation of distinguishable structures.

The model is formulated from a nonlinear Lagrangian dependent on the kinetic invariant $X = \nabla\mu Z \nabla\mu Z$, incorporating a logarithmic term that introduces a natural mechanism of regulation and saturation in high-energy regimes, in accordance with the framework of effective field theories developed by Steven Weinberg. This term prevents the unbounded growth of invariant quantities and allows the notion of singularity to be replaced by regimes of controlled high curvature. In cosmology, models based on effective scalar fields have proven to be versatile tools for describing both the dynamics of the early universe and late-universe acceleration (Carroll, 2001).

Within this framework, gravity emerges as a geometric response to the effective energy generated by the Z field, while spatial variations in the field can reproduce phenomena typically attributed to dark matter, such as the approximately flat galactic rotation curves observed by Vera Rubin and colleagues, as well as Tully–Fisher-type relationships established by Richard B. Tully and J. Richard Fisher, without necessarily requiring the introduction of particulate dark matter. Furthermore, the cosmological behavior of the model is consistent with an effective regime characterized by a state parameter $w \approx -1$, in agreement with observations of the accelerated expansion of the universe reported by Adam Riess and Saul Perlmutter.

Within this framework, dark matter is not interpreted as a fundamental component, but rather as an effective manifestation of the nonlinear and partially saturated regime of the Z field. In this regime, the field's gradients generate additional gravitational effects without requiring the introduction of particle dark matter, providing a unified description of the observed phenomenology.

From a conceptual perspective, the field Z acts as an order parameter that determines the system's dynamic regime. In the absence of gradients, the system is in a pre-geometric state in which distance, time, and physical structure cannot be defined. The appearance of finite gradients allows for the organization of correlations, giving rise to the emergence of geometry, causality, and temporal evolution. In this sense, quantum mechanics can be interpreted as the description of a regime of high coherence, while classical behavior emerges through decoherence processes associated with the redistribution of correlations.

This type of interpretation is consistent with the modern framework of quantum decoherence, in which the classical–quantum transition emerges dynamically from the interaction between degrees of freedom (Zurek, 2003).

This work is part of a previous line of research developed by the author (Pérez Cortes, 2026a, 2026b), in which the relationship between cosmological expansion, the emergence of time, and the possible unification of general relativity and quantum mechanics has been explored. In this extension, an effective formalism is proposed that is capable of connecting the microscopic dynamics of correlations with observable gravitational and cosmological phenomena.

Taken together, the proposal suggests a unified reinterpretation of geometry, matter, and quantum dynamics as manifestations of the same underlying structure, providing a coherent and framework within effective field theory that is potentially testable against astrophysical and cosmological observations.

A preliminary version of this work was registered on Zenodo (DOI: 10.5281/zenodo.18640441). This version introduces fundamental equations for the Z-axis (equilibrium 0.5) and the logarithmic brake$(\zeta R(2ln)R)$.

Development

1. Fundamentals of the Model

1.1 Definition of the effective scalar field (Z)

The field(Z) is introduced as an effective scalar variable that encodes the macroscopic organization of correlations in the underlying system. In this framework, space and time are not fundamental entities, but rather emergent descriptions of the field's dynamics.

The system exhibits a dynamic equilibrium point in ($Z = 0.5$) , around which the deviation ($\phi = Z - 0.5$) is defined.

Spatial variations of the field generate gradients and correlations that allow for the emergence of an effective metric structure, without assuming a prior geometry. In this sense, (Z) acts as an order parameter: the physical structure and the notion of distance emerge only when there are finite spatial variations of the field.

The dynamics are described by a variational principle in which the physically realizable configurations are those that remain stable around equilibrium.

Geometry emerges only when there are finite gradients of the field, that is, when ($\nabla Z \neq 0$) .

Fundamental Scalar Field: An effective variable describing the state of coherence/information of the physical system.

$$\left[Z = \frac{1}{2}\text{In}\left(1 + \frac{X}{M^4}\right) + \alpha A_\mu A^\mu\right]$$

- (Z): macroscopic observable
- (X): kinetic invariant
- (A_μ): underlying vector field
- (M): mass scale
- (α): coupling parameter

The Z field is like an emergent (coarse-grained) effective variable that encodes, on a macroscopic scale, the collective state of the underlying field $A\mu$. In this context, the logarithmic term acts as a nonlinear function of the kinetic invariant, introducing a dynamic compression mechanism that smooths the growth of the effective functional at high energies and contributes to the regularization of the system in the ultraviolet regime.

The term incorporates a direct contribution from the vector field, coupling microscopic degrees of freedom into an effective variable.

Within the framework of the model, it acts as an emergent variable that summarizes the collective state of the physical system, translating the dynamics of the underlying field into a stable macroscopic description.

Z 's functional form is constructed as a combination of:

1. **Logarithmic term:**

$ln\left(1 + \frac{X}{M^4}\right)$

1. **Quadratic term in the field:**

$A_\mu A^\mu$

This combination ensures:

- linear behavior for $X \ll M^4$
- smooth saturation for $X \gg M^4$
- direct coupling to the fundamental degrees of freedom

The field$Z$ is not fundamental, but rather an emergent variable that encodes the collective state of the system.

- The logarithmic term describes the multiscale accumulation of fluctuations
- The $A_\mu A^\mu$ term incorporates direct information from the underlying field
- Taken together, Z acts as an effective measure of coherence and information

Z it represents the macroscopic state of correlations in the system.

- For $X \ll M^4$:

$Z \approx \frac{X}{2M^4}$

- For $X \gg M^4$:

$Z \sim \ln X$

- Introduces a natural mechanism of:
    - UV regularization
    - information compression
    - transition between physical regimes

Z It does not describe particles, but rather the organization of the system's information.

Z is a real scalar field at the fundamental level, whose description in the quantum regime admits an effective complex phase–amplitude representation.

Metric of the Intermediate Filter Z as a Fundamental Physical Agent

The Z field is proposed as a dynamic field that organizes the system's degrees of freedom, not as a passive element.

In this framework:

- General relativity describes the geometric regime when the metric is continuous.
- Quantum mechanics describes the evolution of states and correlations without a defined classical geometry.

The Z field acts as a common structure from which:

- Geometry emerges as a collective property.
- Quantum dynamics is interpreted as the evolution of correlations.

Thus, phenomena such as spacetime, matter, and gravity are understood as emerging from different regimes of the system.

This approach does not establish Z as a final description, but rather as a unifying candidate that allows physics to be interpreted as a manifestation of a common dynamics yet to be formalized.

1.2 Equilibrium state

The value ($Z = 0.5$) defines the single point of symmetry at which deviations ($\phi = Z - 0.5$) can organize themselves in a balanced manner, allowing for stable configurations with finite gradients.

If the equilibrium shifts, this symmetry is broken, introducing a bias into the dynamics that prevents the compensation of fluctuations and reduces the stability of correlations. As a consequence, configurations tend toward regimes dominated by saturation or uniformity, where the structure cannot be sustained persistently.

Thus, ($Z = 0.5$) is not an arbitrary value, but the only point at which the dynamics allow for a symmetric organization of fluctuations, a necessary condition for the existence of gradients, correlations, and stable physical structure.

Equilibrium State Z = 0.5:

The equilibrium state of the system is defined as the configuration in which the effective field Z takes the constant value:

$Z = 0.5$

In this state, the field is homogeneous and exhibits no spatial or temporal variations:

$\nabla_\mu Z = 0$

- (Z): order parameter of the system
- (0.5): fixed-point attractor (equilibrium state)

The equilibrium state is identified as the configuration in which:

1. The field exhibits no local variations:

$\nabla_\mu Z = 0$

2. The associated kinetic invariant is zero:

$X = \nabla_\mu Z \nabla^\mu Z = 0$

3. The system is at an effective minimum of the potential:

$\frac{dV}{dZ}|_{Z=0.5} = 0$

These conditions define a stable fixed point of the dynamics.

$\boxed{Z = 0.5 \ \ , \qquad \nabla_\mu Z = 0}$

1.3 Kinetic invariant

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

- Fundamental dynamic scalar
- Controls gradients

Definition of (X): Kinetic scalar of the field

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

- ($\nabla_\mu Z$): covariant derivative of the field
- (X): invariant scalar associated with the field gradient

The scalar (X) represents the local rate of change of the field (Z) in spacetime.

It directly connects:

- the spatial and temporal structure of the field
- the effective kinetic energy of the system

X is the fundamental quantity that:

- controls the dynamics of the field
- determines the nonlinear behavior of the system

X is the central dynamic invariant of the model**.**

In this framework:

- large values of (X) → regions with steep gradients
- small values of (X) → configurations close to equilibrium

Therefore: X = local measure of the dynamic activity of the field

1**.4 Deviation of ϕ**

Deviation from Equilibrium: A measure of symmetry breaking; the origin of all observable physics.

The local deviation from equilibrium is defined as:

$$[\phi(x) = Z(x) - 0.5]$$

- (ϕ): local deviation from equilibrium
- ($Z(x)$): effective field
- (0.5): equilibrium value (fixed point)

All observable physics (particles, gravity, time) arises when ($\phi \neq 0$).

This variable measures how far the system deviates from the state of maximum coherence.

Since the equilibrium state is defined by:

$$Z \ = \ 0.5$$

it is natural to introduce a centered variable:

$$\phi(x) = Z(x) - 0.5$$

This transformation allows us to:

- describe the dynamics around equilibrium
- clearly separate the background (vacuum) from the excitations

- formulate the theory in terms of physical degrees of freedom

$\boxed{\phi(x) = Z(x) - 0.5}$

The variableϕ represents the local breaking of the system's symmetry:

- $\phi = 0 \rightarrow$ perfect equilibrium (no observable physics)
- $\phi \neq 0 \rightarrow$ emergence of structure

ϕ represents the physical content of the universe.
In this regard:

- ϕ 's fluctuations correspond to excitations of the system
- ϕ 's dynamics describe observable physical evolution

All of physics emerges when:
$\phi \neq 0$
This includes:

- **particles:** localized excitations of ϕ
- **gravity:** gradients of ϕ
- **time:** evolution of ϕ
- **structure:** inhomogeneous configurations

Additionally:

- the linear regime corresponds to:

$$|\phi| \ll 1$$

- the nonlinear regime corresponds to:

$$|\phi| \sim 1$$

The universe is not described by Z , but by ϕ ; equivalently, all of physics corresponds to deviations from equilibrium. The observable universe is not equilibrium, but its deviations; $Z = 0.5$ represents a state of pure coherence without classical physics.

1.5 Dynamic domain of the field

The extreme values ($Z \rightarrow 0$) y ($Z \rightarrow 1$) do not represent independent physical states, but rather limit configurations in which structure ceases to be meaningful.

At the limit ($Z \rightarrow 0$) , gradients and correlations cancel out, leading to a uniform state with no distinguishable structure.

At the limit ($Z \rightarrow 1$) , the system enters a saturation regime in which, despite the maximum value of the field, the absence of variations prevents the formation of structure and evolution.

The only relevant dynamic domain is the vicinity of the equilibrium ($Z = 0.5$) , with ($\phi = Z - 0.5$) , where fluctuations can coexist, correlations can form, and stable configurations can emerge.

Physical structure including geometry, causality, and evolution appears only when finite field gradients exist. In their absence, neither distances nor dynamics can be defined.

Thus, physics does not arise from extreme states, but from the intermediate regime in which variations in (Z) allow for the stable organization of structure.

1**.6 Gradient–Deviation Relationship**

Gradient–deviation relation: Connection between the deviation from equilibrium and the spatial structure of the field

An order-of-magnitude estimate is introduced that relates the deviation of the field to the intensity of its gradients:

$$\left[X \sim \frac{\phi^2}{L^2}\right]$$

where (L) represents the characteristic scale of spatial variation of the field.

This relationship is obtained under the assumption of smooth variations:

$$\left[\nabla_\mu Z \sim \frac{\Delta Z}{L}, \quad \Delta Z \sim \phi\right]$$

hence:

$$\left[X = \nabla_\mu Z \nabla^\mu Z \sim \frac{\phi^2}{L^2}\right]$$

This approximation is valid in regimes where the field exhibits smooth variations and can be characterized by a dominant effective scale.

This relationship is valid in the regime of smooth field variation, characterized by:

$$[X \ll \Lambda^4]$$

- (ϕ): deviation from equilibrium
- (L): characteristic scale
- ($X = \nabla_\mu Z \nabla^\mu Z$): gradient intensity, kinetic scalar

Heuristic derivation

For a typical spatial variation of the field:

$\left[\nabla_\mu Z \sim \frac{\Delta Z}{L}\right]$

identifying:

$[\Delta Z \sim \phi]$

we obtain:

$\left[X = \nabla_\mu Z \nabla^\mu Z \sim \frac{\phi^2}{L^2}\right]$

The spatial structure of the field is directly linked to its deviation from equilibrium:

[desviación ⇒ estructura]

In this framework:

- greater (ϕ) → greater gradient intensity
- smaller (L) → more concentrated structures

L represents the characteristic scale of the dominant mode or the correlation length of the system.

Geometry–energy connection

- gradients determine the effective energy
- deviation controls gradient generation

Physical scales

- (L) sets the characteristic size of the structures
- controls the spatial distribution of field information

Consistency with (N_{local})

$$\left[X \sim \frac{\phi^2}{L^2}\right]$$

(in units where ($L \sim 1$))

$[X \sim \phi^2 \quad \Rightarrow \quad N_{\mathrm{local}} \sim \phi^2]$

This relationship is valid as an order-of-magnitude estimate in regimes of smooth field variation

1**.7 Dynamic restriction of configurations**

- Stability → physical subset
- Inconsistent configurations → unachievable

Dynamic Uniqueness and Configuration Constraints

Within the framework of the field (Z), not all mathematically possible configurations are physically realizable. The equilibrium ($Z = 0.5$) imposes conditions of symmetry and stability on the deviations ($\phi = Z - 0.5$) , restricting those capable of sustaining finite gradients and coherent correlations.

Configurations that do not satisfy these conditions are not excluded by an external principle, but rather are dynamically unstable and evolve toward regimes of saturation or uniformity, where the structure cannot persist.

As a consequence, the set of physical configurations constitutes a restricted subset of the total space of possibilities.

In this sense, the existence of multiple universes is not formally ruled out, but it is conditioned on dynamic stability: only those configurations that maintain coherence around equilibrium can give rise to a consistent physical description.

1.**8 Physical Dictionary of the Model**

Overall Structure of the Model

Definitive Conceptual Dictionary: Relationship between terms and physical meaning.

A dictionary is established that connects each mathematical term with its physical meaning within the model, providing a unified interpretation.

$$[Z(x^\mu)][\phi = Z - 0.5]\left[\ln\left(1 + \frac{X}{\Lambda^4}\right)\right][J^\mu][S_Z]\left[\frac{\partial Z}{\partial t}\right]$$

- (Z): effective field
- (ϕ): deviation from equilibrium
- (J^μ): information flow
- (S_Z): entropy

Defines the physical meaning of each term, relates concepts, conceptual structure of the model

$at\ the\ static\ limit: X \approx |\nabla Z|^2$

> **Field $\boldsymbol{Z(x^\mu)}$**

- **Meaning:** state of coherence of the system
- **Interpretation:** describes the overall organization of information

> **Deviation** $\phi = Z - 0.5$

- **Meaning:** disruption of equilibrium
- **Interpretation:** the origin of all observable physics

> **Logarithmic term** $\left[ln\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$

$\ln\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)$

- **Interpretation:** controls the growth of gradients and prevents divergences

> **Flow** $\boldsymbol{J^\mu}$

- **Meaning:** transport of information
- **Interpretation:** system dynamics

> **Entropy** $\boldsymbol{S_Z}$

- **Meaning:** informational content
- **Interpretation:** measure of structure and complexity

> **Temporal evolution** $\boldsymbol{\frac{\partial Z}{\partial t}}$

$$\frac{\partial Z}{\partial t}$$

- origin of emergent time

The field defines coherence; deviation generates observable physics; gradients determine forces and dynamics; flow describes evolution; entropy quantifies information; and change defines time.

The model establishes a complete correspondence: every physical quantity is a form of information

> Conceptual unification

- all physical concepts are derived from
- there are no independent entities

> Physical translation

- every equation has a clear meaning
- eliminates interpretive ambiguity

> Basis of the model

- allows any result to be interpreted
- connects mathematics with physics

Physics can be understood as a dictionary of information; equivalently, each mathematical term represents a form of coherence.

2. Potential Structure and Stability

2.1 Effective potential

Equilibrium structure

$$[V(Z) = \lambda(Z - 0.5)^2]$$

This defines a preferred equilibrium state Z = 0.5, around which:

- coherent regimes form
- deviations generate dynamics
- gradients induce curvature.

Z Field Potential: A function that determines the equilibrium structure and stability of the field.

The effective field potential is defined as:

$$[V(Z) = \lambda(Z - 0.5)^2 + \beta(Z - 0.5)^4]$$

- (λ) = quadratic coefficient (local stiffness)
- (β) = quartic coefficient (nonlinear stability)

2.2 Properties of the Potential

It defines the equilibrium point at $(Z = 0.5)$ and controls stiffness against deviations; responsible for restoring the system to its base state.

This potential determines the equilibrium structure and the stability of the system.

The potential is constructed as an expansion around the equilibrium point:

$Z = 0.5$

Defining the deviation:

$\phi = Z - 0.5$

the potential takes the form:

$V(\phi) = \lambda\phi^2 + \beta\phi^4$

This form guarantees:

- a minimum in $\phi = 0$
- symmetry under $\phi \rightarrow -\phi$
- global stability for $\beta > 0$

2.3 Hierarchical Architecture of the Model

Global Architecture of the Model: Logical chain from microstructure to cosmological observables.

The model is organized as a logical chain connecting the microstructure of the underlying field with observable macroscopic phenomena, from internal dynamics to the geometry of spacetime.

$$\left[A_\mu \rightarrow X \rightarrow Z \rightarrow \nabla Z \rightarrow \text{gravedad} \rightarrow \text{geometría}\right]$$

- (A_μ): underlying vector field
- (X): kinetic invariant
- (Z): emerging effective field
- (∇Z): field gradients

The theory is constructed in hierarchical levels:

> Microstructure

- A_μ: fundamental field
- defines the basic dynamics

> Local dynamics

- X: measures system activity
- encodes excitations

> Emergent level

- Z: effective variable (coarse-grained)
- summarizes the information

> Spatial structure

- ∇Z: generates gradients
- defines forces and flow

> Gravitational level

- gradients → acceleration
- gravity emerges

> Geometric level

- correlations → metric
- spacetime emerges

The model is completely closed: all of physics emerges from a single field
In this framework:

- there are no additional fundamental entities
- everything arises from internal dynamics

> Unification

- matter, gravity, and spacetime have a common origin
- eliminates fundamental dualities

> Total Emergence

- Geometry is not fundamental
- time, space, and forces emerge

> Internal consistency

- each level derives from the previous one
- does not require external postulates

> Predictability

- clear structure → clear predictions
- fully traceable model

Reality constitutes a hierarchy of emergences arising from a single field; similarly, geometry is the final layer of an informational chain.

Connects all levels of the model. Requires no external entities.

3. Dynamics

***3*.1 Complete Lagrangian**

$$\left[\mathcal{L} = X - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

General Form of the Lagrangian: Complete expression of the Lagrangian in terms of explicit potential.

The dynamics of the field are expressed in their most general form as:

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

$$\left[\mathcal{L} = X - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

- ($V(Z)$) = field potential
- (ζ) = regulator intensity
- (Z) = effective field
- (Λ) = characteristic scale of the system

It summarizes the complete dynamics of the system as a balance between propagation, stability, and nonlinear regulation.

This formulation explicitly separates the kinetic, potential, and nonlinear control components.

This Lagrangian encodes the entire dynamics of the system:

- the kinetic term generates propagation and information transport
- the potential defines equilibrium and restoration
- the logarithmic term regulates behavior in extreme regimes

***3*.2 Lagrangian of the model**

1. Starting point (Lagrangian)

We take:

$[\mathcal{L} = F(X) - V(Z)]$

where:

$\left[F(X) = \kappa X - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$

We define:

$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$

Complete Lagrangian

The following effective Lagrangian is proposed to describe the dynamics of the field (Z):

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

$$[\mathcal{L}_Z = F(X) - V(Z)]$$

where:

$$\left[F(X) = \kappa X - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

$$[V(Z) = \lambda (Z - 0.5)^2 + \beta (Z - 0.5)^4]$$

- (κ): kinetic stiffness
- (λ): quadratic parameter of the potential
- (β): self-interaction parameter
- (ζ): intensity of the logarithmic term

- (Λ): UV cutoff scale

Explicit form (equivalent)

$$\left[\boxed{\mathcal{L}_Z = \kappa X - \lambda(Z-0.5)^2 - \beta(Z-0.5)^4 - \zeta \ln\left(1+\frac{X}{\Lambda^4}\right)}\right]$$

We define the action:

Action of the system

The action of the system is written as:

$$\left[S = \int d^4\, x, \sqrt{-g}\left[\frac{R}{16\pi G} + \mathcal{L}_Z\right]\right]$$

where:

$$[\mathcal{L}_Z = F(X) - V(Z)]$$

$$\left[F(X) = \kappa X - \zeta \ln\left(1+\frac{X}{\Lambda^4}\right)\right]$$

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

3.**3 Structure of the Lagrangian**

Structure of the Lagrangian

The Lagrangian is constructed as the combination of three fundamental contributions:

1. Kinetic term

$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$

Describes the propagation of the field and the generation of dynamics.

2. General potential

$[-V(Z)]$

Defines:

- the equilibrium of the system
- stability
- the phase structure

3. Logarithmic term

$\left[-\zeta \ln\left(1+\frac{X}{\Lambda^4}\right)\right]$

Introduce:

- high-energy regulation
- gradient saturation

divergence control

Structure of the Lagrangian

1. Dynamics (nonlinear kinetic term)

$[F(X)]$

Describes:

- field propagation
- effective dynamics
- nonlinear corrections

2. Effective potential

$[-V(Z)]$

Define:

- equilibrium at ($Z = 0.5$)
- system stability
- nonlinear behavior

3. Logarithmic term (regulation)

$$\left[-\zeta \ln\left(1+\frac{X}{\Lambda^4}\right)\right]$$

Enter:

- high-energy regulation
- gradient saturation
- divergence control

Physical decomposition

1. Gravitational term

$$\left[\frac{R}{16\pi G}\right]$$

- General Relativity standard
- defines the dynamics of the metric

2. Field dynamics

$[F(X)]$

- generates propagation
- introduces nonlinearity
- produces dynamic saturation

3. Potential

$[V(Z) = \lambda(Z-0.5)^2 + \beta(Z-0.5)^4]$

- sets the equilibrium
- controls stability
- determines structure

4. Logarithmic regulation

$$\left[-\zeta \ln\left(1+\frac{X}{\Lambda^4}\right)\right]$$

- regulates high energies
- prevents divergences
- introduces saturation

Lagrangian Reduced to 2 Parameters: Minimal version with non-redundant parameters.

A minimal version of the Lagrangian for the$Z$ field is introduced, in which redundant parameters are absorbed through rescaling, leaving only two fundamental parameters:

$$\left[\mathcal{L} = (\nabla Z)^2 - \frac{1}{2}\Lambda^2(Z-0.5)^2 - \zeta\text{In}\left(1+\frac{X^2}{\Lambda^4}\right)\right]$$

- (Λ): fundamental coherence scale
- (ζ): intensity or strength of the information brake
- (Z): effective field
- (κ_{eff}): ($\kappa - \zeta/\Lambda^4$) absorbed. Effective kinetic coefficient (absorbed via rescaling)

The entire physics of the model depends on only two parameters: (Λ) and (ζ). Minimal version with non-redundant parameters.

This form captures the essential dynamics of the model with the fewest effective degrees of freedom.

Starting from the general Lagrangian:

- the kinetic coefficient is rescaled to unity
- the potential parameters are combined into a single scale Λ
- higher-order corrections are absorbed into effective terms

In particular:

$$\kappa_{\text{eff}} = \kappa - \frac{\zeta}{\Lambda^4}$$

it is redefined within the kinetic term, eliminating redundancies.

The result is a theory governed solely by:

- an energy scale (Λ)
- a control parameter (ζ)

This Lagrangian shows that the entire dynamics of the system depend on only two fundamental elements:

- Λ = sets the scale at which the system's coherence emerges
- ζ = controls the degree of regulation of the fluctuations

> Structural simplification

- eliminates redundant parameters
- makes the model more predictive
- facilitates comparison with observations

All of the model's physics are governed by scaling and tuning

> Linear regime

For:

$|\nabla Z|^2 \ll \Lambda^4$

the logarithmic term is small:

→ standard behavior

> Nonlinear regime

For:

$Z \neq 0.5$

the quadratic term dominates:

→ return to equilibrium

> Saturation regime

To:

$X \gg \Lambda^4$

The log records:

- dynamic braking
- information compression
- natural physical limit

The complexity of the universe emerges from just two parameters; similarly, ζ, Λ , and ζ determine all of physics.

Logarithmic regulator: A term that controls the growth of gradients.

A logarithmic term is introduced into the field dynamics that controls the growth of gradients:

$$\left[-\text{In}\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

- ($|\nabla Z|^2$): field intensity, magnitude of the field gradient (local intensity).
- (Λ): characteristic cutoff scale

3.4 Dynamic Regimes

Linear

$[X \ll \Lambda^4]$

Nonlinear

$[Z \neq 0.5]$

Saturation

$[X \gg \Lambda^4]$

> Linear regime

For:

$[X \ll \Lambda^4]$

- Standard scalar field behavior

> Nonlinear regime

When the potential dominates:

- structure formation
- stability

> Extreme regime

When:

$[X \gg \Lambda^4]$

- the log term regulates
- prevents divergences
- introduces saturation

Dynamic regimes

> Linear regime

When:

$[X \ll \Lambda^4]$

$[\ln(1 + x) \approx x]$

→ standard scalar field behavior
(compatible with quantum field theory)

> Nonlinear regime

When:

$[Z \neq 0.5]$

the potential generates:

- structures
- stability
- effective interaction

> High-energy regime (saturation)

When:

$[X \gg \Lambda^4]$

the log term introduces:

- slow growth
- dynamic brake
- elimination of divergences

3.5 Field Equation

2. Euler–Lagrange Equation

The general equation is:

$$\left[\nabla_\mu \left(\frac{\partial \mathcal{L}}{\partial(\nabla_\mu Z)}\right) - \frac{\partial \mathcal{L}}{\partial Z} = 0\right]$$

5. Substitution in Euler–Lagrange

$$\left[\nabla_\mu \left[2\nabla^\mu Z \left(\kappa - \frac{\zeta}{\Lambda^4 + X}\right)\right] V'(Z) = 0\right]$$

Final form (field equation of the Z model)

$$\left[\nabla_\mu (F'(X)\, \nabla^\mu Z) + V'(Z) = 0\right]$$

where:

$$\left[F'(X) = \kappa - \frac{\zeta}{\Lambda^4 + X}\right]$$

Field equation

$$\left[\nabla_\mu (F'(X)\nabla^\mu Z) + V'(Z) = 0\right]$$

>Short derivation

3. Derivative with respect to ($\nabla_\mu Z$)

First:

$$\left[\frac{\partial X}{\partial(\nabla_\mu Z)} = 2\nabla^\mu Z\right]$$

> Kinetic part

$$\left[\frac{\partial}{\partial(\nabla_\mu Z)}(\kappa X) = 2\kappa \nabla^\mu Z\right]$$

> Logarithmic part

$$\left[\frac{\partial}{\partial(\nabla_\mu Z)}\left[\ln\left(1 + \frac{X}{\Lambda^4}\right)\right]\frac{1}{\Lambda^4 + X}, 2\nabla^\mu Z\right]$$

> Total result

$$\left[\frac{\partial \mathcal{L}}{\partial(\nabla_\mu Z)} 2\nabla^\mu Z \left[\kappa - \frac{\zeta}{\Lambda^4 + X}\right]\right]$$

4. Derivative with respect to (Z)

Only the potential depends on (Z):

$$\left[\frac{\partial \mathcal{L}}{\partial Z} = -V'(Z)\right]$$

Equation of motion: Dynamics of the Z field.

The dynamics of the field are determined by the following equation of motion, which incorporates propagation and nonlinear damping effects:

$$\left[\nabla_\mu \left(\frac{\nabla^\mu Z}{1 + \frac{|\nabla Z|^2}{\Lambda^4}}\right) = V'(Z)\right]$$

- (Z): effective field
- ($\nabla^\mu Z$): field flux
- ($|\nabla Z|^2$): gradient intensity

- (Λ): characteristic scale
- ($V'(Z)$): potential derivative

Equilibrium between propagation and potential, describes how the structure forms, evolution with nonlinear damping.

The equation is obtained from a Lagrangian with a logarithmic regulator, where:

- the kinetic term generates propagation
- the regulator introduces gradient-dependent damping

This redefines the effective field flux as:

$$\nabla^{\mu} Z \longrightarrow \frac{\nabla^{\mu} Z}{1 + \frac{|\nabla Z|^2}{\Lambda^4}}$$

The equation describes an equilibrium between:

- field propagation
- potential force
- nonlinear damping

The dynamics consist of propagation, potential, and internal damping.
In this framework:

- the field tends toward the equilibrium defined by $V'(Z)$
- but its evolution is governed by its own intensity

> Structure formation

- the potential guides the formation of configurations
- deviations generate observable dynamics

> Nonlinear damping

- large gradients → slower evolution
- prevents instabilities

> Linear regime

For small gradients:

→ standard scalar-field-like behavior

> Extreme regime

For large gradients:

→ the dynamics slow down

→ the system stabilizes

The equation expresses the conservation of information flow; information is neither created nor destroyed, but is conserved through its redistribution.

3.6 Variational current and conservation

Conservation of Flow: Expresses the conservation (or balance) of the field's information flow.

The flow conservation equation is established, describing the conservation (or balance) of information transport in the system.

$$\left[\nabla_{\mu} J^{\mu} = 0\right]$$

- (J^{μ}): information flow
- (∇_{μ}): covariant derivative

From the flux defined by:

$$J^{\mu} = \frac{\partial \mathcal{L}}{\partial(\nabla_{\mu} Z)}$$

the equation of motion can be written as a conservation condition:

$\nabla_\mu J^\mu = 0$
when there are no external sources.

The equation expresses the conservation of information flow; information is neither created nor destroyed, but rather redistributed.
Within this framework:

- the system evolves while conserving its informational content
- the dynamics are internally consistent

> Local conservation

- information is conserved point-to-point
- the flow is well-defined

> Connection with entropy

- The flow carries information
- entropy measures its distribution

> Relationship with causality

- The propagation of the flow respects causal structure
- It defines the temporal evolution

> System dynamics

- All evolution can be interpreted as a redistribution of flow
- There is no spontaneous creation of information

Variational Current: A current obtained directly from the Lagrangian via functional differentiation.

A flux is defined as obtained directly from the Lagrangian via functional differentiation with respect to the field gradient:

$$\left[J^\mu = \frac{\partial \mathcal{L}}{\partial(\nabla_\mu Z)}\right]$$

For the Lagrangian:
$\left[\mathcal{L} = F(X) - V(Z), \quad X = \nabla_\mu Z \nabla^\mu Z\right]$
we obtain:
$[J^\mu = 2F'(X), \nabla^\mu Z]$
where:
$\left[F'(X) = \kappa - \frac{\zeta}{\Lambda^4 + X}\right]$

> Basis of Dynamics

- the equation of motion can be written as:

$\left[\nabla_\mu J^\mu + V'(Z) = 0\right]$

directly connects flow and dynamics

Blocked flow: Horizon = informational blockage.

The horizon is interpreted as a region where the flow of information from the Z field is dynamically blocked.

$$[J^\mu \to 0]$$

- (J^μ): flow

Flow: Transport of information.

J^μ flow is defined as the quantity describing the transport of information in the system, determined by the gradients of the$Z$ field and regulated by nonlinear effects.

$$\left[J^{\mu} = \frac{\nabla^{\mu} Z}{1 + \frac{|\nabla Z|^2}{\Lambda^4}}\right]$$

- (J^{μ}): information flow
- ($\nabla^{\mu} Z$): field gradient
- ($|\nabla Z|^2$): gradient intensity
- (Λ): fundamental scale

3.7 Linear Relativistic Regime (Klein-Gordon Type)

Relativistic field equation (weak limit)

In the weak field regime, where the nonlinear effects associated with the logarithmic term are negligible, the effective scalar field (Z) obeys a Klein–Gordon-type relativistic equation.

This expression corresponds to the effective relativistic form of the field in the absence of nonlinear saturation, ensuring the recovery of standard dynamics in the perturbative limit.

This limit ensures the recovery of standard physics under low-energy conditions.

$$[\Box + V'(Z) = 0]$$

where ($\Box \equiv \partial_{\mu}\partial$) is the d'Alembertian operator.

- (Z): effective scalar field
- ($\Box$): d'Alembertian operator
- ($V(Z)$): effective potential
- ($V'(Z)$): derivative of the potential with respect to (Z)
- (Λ): model cutoff scale

Describes the propagation of the field in the linear regime; a bridge between classical dynamics and quantum mechanics.

3.8 Classical Regime

Classical Limit: A regime in which the model returns to standard physics.

$$\left[|\nabla Z|^2 \ll \Lambda^4 \Rightarrow \mathrm{In}\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right) \approx \frac{|\nabla Z|^2}{\Lambda^4}\right]$$

- (Λ) = cutoff scale

The model reduces to a standard scalar field and reproduces general relativity in the weak limit.

The classical limit is defined as the regime in which the field variations are small compared to the characteristic scale Λ :
$|\nabla Z|^2 \ll \Lambda^4$

3.9 Stability functional (variational generalization)

Stability functional: Generalization of the action.

The stability functional is introduced as a generalization of the action principle, in which the dynamics of the system are weighted by a coherence filter:

$$\left[\mathcal{J} = \int W(Z)\mathcal{L}_Z\right]$$

- ($W(Z)$): stability filter
- ($\mathcal{L}_Z$): Lagrangian
- (Z): effective field

The system selects stable states.

It redefines the system's dynamic criterion in terms of effective stability.

Starting from the standard principle:

$S = \int \mathrm{c}L$

a modification is introduced:

$\mathcal{L} \longrightarrow W(Z)\, \mathcal{L}_{\mathcal{Z}}$

where $W(Z)$ acts as a dynamic weight that depends on the state of the system.

This generalization implies that:

- the dynamics no longer depend solely on the Lagrangian
- the relevance of each configuration is modulated by its stability

The parameter $\mathcal{J}$ determines that: the system selects stable states

In this framework:

- the principle of action becomes a principle of selection
- the dynamics favor coherent configurations
- the system's evolution is guided by effective stability

> Dynamic selection

- stable states → dominate the dynamics
- unstable states → suppressed

> Generalization of the variational principle

- classical action is a limiting case
- the functional introduces a richer structure

> Conceptual interpretation

- physics is not just about extremization
- it is the selection of physically realizable configurations

Action generalizes to a principle of stability selection; equivalently, the dynamics of the universe are dynamics of selection.

Stability Functional (Complete Form): A fully defined version of the system's variational functional.

The complete form of the stability functional is defined as the integral of the Lagrangian weighted by a coherence filter over all of spacetime:

$$\left[\mathcal{S}[Z] = \int d^4\, x W(Z) \mathcal{L}_{\mathcal{Z}}\right]$$

- $(d^4 x)$ = spacetime volume
- $(W(Z))$ = stability/coherence filter
- $(\mathcal{L}_{\mathcal{Z}})$: complete Lagrangian of the field
- (Z): effective field

It integrates the dynamics weighted by stability over all of spacetime.

This expression constitutes the fully defined version of the system's variational principle.

The functional is constructed as:

1. **Integration over spacetime**

$\int d^4\, x$

2. **Coherence weighting**

$W(Z)$

3. **Local dynamics**

$\mathcal{L}_{\mathcal{Z}}$

The combination produces a global measure of the system's stability.

It represents the global dynamics weighted by stability; the evolution of the system results from the sum of coherent contributions throughout space-time.

In this framework:

- each region contributes according to its degree of coherence
- stable configurations dominate the global dynamics
- unstable configurations are suppressed

> Coherent global dynamics

Evolution depends not only on local laws, but also on:

- global integration
- accumulated stability

> Recovery of the standard case

If:
$W(Z) = 1$

→ the classic action is restored:
$S = \int d^4 x \, \mathcal{L}_Z$

> Selection of physical configurations

- regions near equilibrium → greater weight
- extreme regions → lower effective contribution

> Cosmological interpretation

The universe can be understood as:

- a sum of coherent regions
- governed by global stability

Physics is described by a stability integral rather than merely a dynamics integral; equivalently, the universe is organized by accumulated coherence in spacetime.

Stability Functional: Replaces the classical minimum action; the system maximizes coherence rather than minimizing action.

A stability functional $\mathcal{S}[Z]$ is introduced that generalizes the principle of action, incorporating a filter that weights configurations according to their degree of coherence:

$$\left[\mathcal{S}[Z] = \int d^4 \, x W(Z) \mathcal{L}_Z\right]$$

- ($W(Z)$): Gaussian stability filter (Gaussian type)
- ($\mathcal{L}_Z$): full Lagrangian of the field
- (Z): effective field

If ($W \approx 1$) (near equilibrium), the classical action is recovered. The system selects configurations that are dynamically stable.

- configurations
- stability
- filter

This functional replaces the classical criterion of minimum action with a selection principle based on dynamic stability.

In the standard formulation:

$S = \int d^4 x \, \mathcal{L}$
and the dynamics are obtained by minimizing the action.

In this framework, a weighting is introduced:

$\mathcal{L} \longrightarrow W(Z) \, \mathcal{L}_Z$
where $W(Z)$ acts as a filter that favors configurations close to equilibrium.

This modification implies that:

- not all configurations contribute equally
- the most coherent configurations have greater dynamic weight

The system does not select configurations based on minimum action in the strict sense, but rather on maximum effective coherence: the dynamics favor stable and coherent configurations

In this sense:

- $W(Z)$ it acts as a dynamic selector
- it penalizes extreme deviations
- it reinforces physically feasible configurations

> Recovery of the classical limit

When:

$W(Z) \approx 1$

near equilibrium ($Z = 0.5$):

→ the standard principle of action is restored

> Dynamic selection of configurations

- unstable configurations → suppressed
- coherent configurations → dominant

> Statistical interpretation

The functional can be interpreted as:

- an effective weight on configurations
- a measure of system coherence

> Relationship with the logarithmic controller

- both introduce control mechanisms
- both limit extreme behaviors
- both promote stability

Dynamics is a principle of coherence, not just of extreme action.

3.10 Coherence Filter $W(Z)$

Quantum Collapse as "Coherence Filtering"

Z Filter: A selection operator that weights configurations according to their proximity to equilibrium.

$$\left[W(Z) = exp\left[-\frac{(Z-0.5)^2}{\sigma^2}\right]\right][\mathcal{F}_Z[\phi] = \mathrm{W(Z)}\phi]$$

- (σ): filter width
- ($W(Z)$): weight
- (ϕ): deviation

The system dynamically favors states close to equilibrium. It does not eliminate states; it weights them. It is an emergent selection mechanism, not an imposed one.

The filter is introduced as a selection operator that dynamically weights the system's configurations according to their proximity to equilibrium:

$$W(Z) = exp\left[-\frac{(Z-0.5)^2}{\sigma^2}\right]$$

and its action on deviations is defined as:

$\mathcal{F}_Z[\phi] = W(Z)$

The filter is constructed by imposing:

1. **Maximum at equilibrium**

$Z = 0.5 \Rightarrow W = 1$

2. **Smooth suppression of deviations**

$|Z - 0.5| \uparrow \Rightarrow W$

3. **Smoothness and positivity**

$0 < W(Z) \leq 1$

The Gaussian distribution is the simplest solution that satisfies:

- symmetry around the equilibrium
- continuous decay
- mathematical stability

The filter $W(Z)$ acts as a dynamic selection operator:

- it does not eliminate configurations
- it weights them according to their stability

The system favors states close to equilibrium.

In this context:

- equilibrium is the most "probable" state dynamically
- large deviations are suppressed, but not prohibited

> **State selection**

- states with $|Z - 0.5| \ll \sigma \rightarrow$ dominant
- states with $|Z - 0.5| \gg \sigma \rightarrow$ suppressed

> **Effective dynamics**

The field evolves under:

- Lagrangian terms
- filter weight

> **Statistical interpretation**

The filter can be interpreted as:

- a measure of coherence
- an effective probability
- a dynamic weight

> **Model robustness**

- prevents extreme instabilities
- introduces global stability
- maintains system continuity

Nature does not eliminate states, but rather weights them; similarly, reality is a smooth selection of configurations.

Z-filter: Stability weight.

The filter $W(Z)$ is defined as a stability weight that assigns a value to each system configuration based on its proximity to equilibrium:

$$\left[W(Z) = exp\left[-\frac{(Z - 0.5)^2}{\sigma^2}\right]\right]$$

- $(Z\ )$: effective field
- $(\sigma\ )$: parameter that changes the filter width

Selects states close to equilibrium, weights configurations, favors states close to equilibrium.

The filter is constructed by imposing:

- maximum at equilibrium:

$Z\ =\ 0.5\ \Rightarrow W\ =\ 1$

- continuous suppression of deviations:

$|Z - 0.5|\ \uparrow\Rightarrow W$

- symmetry with respect to equilibrium

The Gaussian distribution is the minimal choice that satisfies these conditions.

The $W(Z)$ filter acts as a weight that measures the stability of a configuration: it favors states close to equilibrium.
In this sense:

- values close to $Z\ =\ 0.5$ → high stability
- values far away → lower dynamic weight

> Configuration weighting

- the system does not eliminate states
- assigns relevance based on stability

> Dynamic selection

- Configurations close to equilibrium → dominate
- Configurations far from equilibrium → contribute less

> Control of dynamics

The parameter σ:

- defines the tolerance for deviations
- controls the width of the stable regime

Stability is encoded as a dynamic weight; equivalently, equilibrium is not mandatory, but it is preferred.

3.11. Quantum Uncertainty as an Emergent Property

Within the framework of the present model, Heisenberg's uncertainty relation can be reinterpreted as an emergent manifestation of the high-coherence regime of the effective field (Z) , rather than as an independent fundamental principle.

In states close to equilibrium $(Z = 0.5)$, the correlations among the system's degrees of freedom are maximal and do not admit a decomposition into independent classical variables. In this regime, the fluctuations of the field $(\phi = Z - 0.5)$ are strongly coupled, preventing the simultaneous assignment of definite values to conjugate quantities without altering the global structure of the system.

Thus, the uncertainty relation can be interpreted as a collective property of the correlation state, rather than as a fundamental limitation of measurement.

This idea can be formalized by introducing an effective Planck constant dependent on the dynamic state of the field:

$$[\Delta x, \Delta p \sim \hbar_{\text{eff}}(Z, X),]$$

where $\left(X = \nabla_\mu Z \nabla^\mu Z\right)$ is the kinetic invariant. In this context, it is natural to extend the effective commutation relation as:

$\left[[x, p] = i\hbar_{\text{eff}}(Z, X).\right]$

Consistent with the structure of the Lagrangian,

$\left[\mathcal{L} = X - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right),\right]$

it is proposed that the effective coherence of the system is governed by the same regulatory mechanism that controls the gradients. This leads to a functional dependence of the form:

$$\left[\hbar_{\mathrm{eff}}(X) = \hbar_0, \frac{1}{1+\frac{X}{\Lambda^4}},\right]$$

where($\hbar_0$) corresponds to the value observed in the standard quantum regime.

This expression reproduces the different physical regimes of the model:

For ($X \ll \Lambda^4$): [$\hbar_{\mathrm{eff}} \approx \hbar_0$,]
, recovering conventional quantum mechanics.

For ($X \gg \Lambda^4$): [$\hbar_{\mathrm{eff}} \to 0$,]
, which induces effective classical behavior.

In this framework, the quantum–classical transition is interpreted as a dynamic loss of coherence associated with the growth of field gradients. This process can be identified with the redistribution of large-scale correlations, in particular with cosmological expansion.

As a consequence, quantum uncertainty emerges as a property dependent on the system's state: it is maximal in high-coherence regimes and is progressively suppressed as the system evolves toward less correlated configurations.

This interpretation suggests that quantum mechanics constitutes an effective regime of the theory, characterized by ($X \ll \Lambda^4$) , in which Planck's constant can be considered approximately constant.

4. Emergent Gravity

*4.***1 Energy–momentum tensor**

$$\left[T_{\mu\nu} 2F'(X)\nabla_\mu Z \nabla_\nu Z g_{\mu\nu\mathcal{L}}\right]$$

Relativistic limit:

Obtained via full coupling to $g_{\mu\nu}$.

The energy–momentum tensor is obtained by functional variation of the action with respect to the metric, resulting in:

$$\left[S = \int d^4 x \sqrt{-g}, \mathcal{L}(Z, X)\right]$$

where:

$$\left[X = \nabla_\mu Z \nabla^\mu Z\right]$$

The energy-momentum tensor is defined as:

$$\left[T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\mu\nu}}\right]$$

Variation of the Lagrangian

The Lagrangian:

$$[\mathcal{L} = F(X) - V(Z)]$$

where:

$$\left[F(X) = \kappa X - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

Energy-Momentum Tensor: Links the model to general relativity; derived from the metric variation of the functional.

$$\left[T_{\mu\nu} = F(X), \partial_\mu Z, \partial_\nu Z - g_{\mu\nu\mathcal{L}}\right]\left[F(X) = 2\kappa - \frac{2\zeta}{\Lambda^4\left(1 + \frac{X}{\Lambda^4}\right)}\right]$$

- ($T_{\mu\nu}$): energy-momentum tensor

- ($F(X)$): effective gradient function
- ($\partial_\mu Z$): field derivative
- ($g_{\mu\nu}$): spacetime metric
- ($\mathcal{L}$): field Lagrangian
- (X) ($|\nabla Z|^2$): kinetic invariant

Connects the model to general relativity. The first term is the dynamic flux; the second is the vacuum pressure/energy. The energy depends on how far from equilibrium the system is.

The energy–momentum tensor $T_{\mu\nu}$ is obtained by varying the functional with respect to the metric, providing the connection between the dynamics of the field$Z$ and the geometry of spacetime: $T_{\mu\nu} = F(X), \partial_\mu Z, \partial_\nu Z - g_{\mu\nu\mathcal{L}}$

where the function $F(X)$ incorporates the effects of the nonlinear regulator:

$$F(X) = 2\kappa - \frac{2\zeta}{\Lambda^4\left(1 + \frac{X}{\Lambda^4}\right)}$$

The tensor is obtained by:

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\backslash delta\, S}{\delta g^{\mu\nu}}$$

Applying this definition to the Lagrangian:

- the kinetic term produces flux-like contributions
- the logarithmic term modifies the dynamic coefficient
- the potential term contributes as effective energy

This leads to a general structure:

$T_{\mu\nu} = (\text{flujo}) - (\text{presión/energía})$

Energy is not fundamental, but rather emerges from the structure of the field; equivalently, gravity responds to the organization of correlations.

In particular:

- the first term represents the dynamic flux of the field
- the second term corresponds to vacuum pressure and energy

> Gravitational source

- $T_{\mu\nu}$ acts as a source in Einstein's equations
- directly connects the field Z with the curvature

> Nonlinear dependence

- The energy depends on X
- gradients modify the effective density

> High-energy regulation

For:

$X \gg \Lambda^4$

→ the correction term reduces $F(X)$

→ the effective energy is limited

> Interpretation of the vacuum

- including without gradients,$\mathcal{L}$ contributes
- defines the system's background energy

Energy is not fundamental and emerges from the structure of the field; equivalently, gravity responds to the organization of correlations.

- The theory does not replace general relativity

- It reproduces it as a geometric framework

The energy-momentum tensor is obtained from the variation of the action with respect to the metric:

$$\left[T_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S}{\delta g^{\mu\nu}}\right]$$

For the Lagrangian:

$$\left[\mathcal{L} = \kappa X - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

with$\left(X = \nabla_\mu Z \nabla^\mu Z\right)$, we obtain:

$$\left[T_{\mu\nu} = 2\kappa \nabla_\mu Z \nabla_\nu Z \kappa g_{\mu\nu} X \frac{2\zeta}{\Lambda^4}\frac{\nabla_\mu Z \nabla_\nu Z}{1 + X/\Lambda^4} g_{\mu\nu}\left[V(Z) - \zeta l\, n\left(1 + \frac{X}{\Lambda^4}\right)\right]\right]$$

4.2 Conservation of the energy-momentum tensor

Conservation of energy.

The conservation of energy and momentum in the system is guaranteed by the covariant conservation of the energy-momentum tensor:

$$\left[\nabla_\mu T^{\mu\nu} = 0\right]$$

- ($T^{\mu\nu}$): energy-momentum tensor
- (∇_μ): covariant derivative

Origin of conservation

Conservation follows from:

- the diffeomorphic invariance of the action
- the Bianchi identities in General Relativity

Given that:

$$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$$

and since:

$$\left[\nabla_\mu G^{\mu\nu} = 0\right]$$

it necessarily follows that:

$$\left[\nabla_\mu T^{\mu\nu} = 0\right]$$

Interpretation

This equation expresses the local conservation of:

- energy
- momentum

Energy is neither created nor destroyed: it is redistributed.

Physical consequences

> Consistency with general relativity

- the model is compatible with the standard geometric structure
- It does not violate fundamental principles

> Local conservation

- Energy is conserved at every point in spacetime
- The energy flux is well-defined

> Field dynamics

- the equations of motion respect this conservation
- The system evolves in a coherent manner

Conservation is a direct consequence of the system's symmetry.
or equivalently:
energy may emerge dynamically, but it remains conserved.
Conservation
We start from the Lagrangian of the effective scalar field:
$\left[\mathcal{L} = F(X) - V(Z), \quad X = \nabla_\mu Z \nabla^\mu Z\right]$
and the previously obtained energy-momentum tensor:
$\left[T_{\mu\nu} 2F'(X) \nabla_\mu Z \nabla_\nu Z - g_{\mu\nu\mathcal{L}}\right]$
Key result
The covariant conservation of the energy-momentum tensor is given by:
$\left[\nabla_\mu T^{\mu\nu} = 0\right]$
This relation is not imposed ad hoc, but is directly deduced from:

- the diffeomorphic invariance of the action
- the equation of motion of the field

Proof (formal summary)
When deriving the energy-momentum tensor, we obtain:
$\left[\nabla_\mu T^{\mu\nu} 2\nabla_\mu\left(F'^{(X)\nabla^\mu} Z\right)\nabla^\nu Z + 2F'^{(X)\nabla^\mu} Z \nabla_\mu \nabla^\nu Z - \nabla^\nu \mathcal{L}\right]$
Using the field equation:
$\left[\nabla_\mu (F'(X)\nabla^\mu Z) + V'(Z) = 0\right]$
the dynamic terms cancel out, resulting in:
$\left[\nabla_\mu T^{\mu\nu} = 0\right]$
4.3 Gravitational Action

$$\left[S = \int d^4\, x\sqrt{-g}\left(\frac{R}{16\pi G} + \mathcal{L}\right)\right]$$

To incorporate gravity, we consider the total action:
$\left[S = \int d^4\, x\sqrt{-g}\left(\frac{R}{16\pi G} + \mathcal{L}_Z\right)\right]$
Variation of the action
The variation with respect to the metric leads to:
$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$
where $\left(T_{\mu\nu}\right)$ corresponds to the field tensor (Z).

Complete Covariant Action: Total action of the system that includes gravity and the Z field in a fully relativistic framework.

The total action of the system is defined as the combination of the geometric dynamics of spacetime and the dynamics of the effective field$Z$, within a fully covariant framework:

$$\left[S = \int d^4\, x\sqrt{-g}\left[\frac{1}{16\pi G} R + \mathcal{L}_Z\right]\right]$$

- (g) = metric determinant
- (R) = Ricci scalar
- (G) = gravitational constant
- ($\mathcal{L}_Z$) = field Lagrangian

It describes the joint dynamics of geometry and the Z field; it ensures covariant invariance and consistency with general relativity.

This action describes the evolution of the field and the geometry in a unified manner.

1. Gravitational sector

$\frac{1}{16\pi G} R$

Corresponds to the Einstein-Hilbert action, which describes the dynamics of the geometry of spacetime.

2. Field sector Z

$\mathcal{L}_Z$

Contains:

- kinetic term
- potential
- logarithmic correction

and describes the internal dynamics of the system.

3. Covariant measurement

$\sqrt{-g}\, d^4x$

Guarantees:

- invariance under coordinate transformations
- relativistic consistency

This action describes a system in which:

- geometry and the field co-evolve Z
- gravity remains as a geometric dynamic
- the h Z field acts as an effective source

The dynamics of the universe result from the interaction between geometry and correlations.

> Modified Einstein equations

Varying with respect to the metric:

$\delta S/\delta g_{\mu\nu} = 0$

equations of the form:

$G_{\mu\nu} = 8\pi G\, T_{\mu\nu}^{(Z)}$

where the field$Z$ generates the energy-momentum tensor.

> Field dynamics

By varying with respect Z :
$\delta S \,/\, \delta Z = 0$

the complete equation of motion for the field is obtained.

> Unified Interpretation

- gravity = geometry
- matter = excitations of Z
- energy = field dynamics

> Effective regime

Under mild conditions:

- standard general relativity is restored
- Z acts as an additional effective field

Under extreme conditions:

- nonlinear corrections appear

- curvature is regulated

Gravity is not independent, but is coupled to the correlation structure; equivalently, spacetime and information evolve together.

Metric Variational Principle: A fundamental condition that determines the dynamics of the system through variation of the total action.

The dynamics of the system are determined by the variational principle applied to the total action. In particular, the geometry of spacetime is obtained by imposing the condition of stationarity of the action with respect to variations of the metric:

$$\left[\frac{\delta\, \mathrm{S}}{\delta\, \mathrm{g}_{\mu\nu}} \;=\; 0\right]$$

- ($g_{\mu\nu}$) = spacetime metric
- (S): total covariant action of the system

4.4 Einstein's Equations

$$\left[G_{\mu\nu} = 8\pi G T_{\mu\nu}\right]$$

Einstein-type equations

$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$

where:

$\left[T_{\mu\nu} = 2F'(X), \nabla_\mu Z \nabla_\nu Z - g_{\mu\nu}[F(X) - V(Z)]\right]$

Explicit form

$\left[T_{\mu\nu} = \left(2\kappa - \frac{2\zeta}{\Lambda^4 + X}\right)\nabla_\mu Z \nabla_\nu Z - g_{\mu\nu}\left[\kappa X - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]\right]$

Derivation of the Einstein Equations: The Einstein equations emerge by imposing local thermodynamic equilibrium on the entropy of Z.

Einstein's equations arise when a condition of local thermodynamic equilibrium is imposed on the entropy of the$Z$ field, relating changes in information to changes in energy.

$$[\delta S_Z \sim \delta E]\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$$

- (δS_Z): entropy variation
- (δE): energy variation
- ($G_{\mu\nu}$): Einstein tensor
- ($T_{\mu\nu}$): energy-momentum tensor

Emergent Einstein Equations: Relativistic geometry emerges from the correlations of the Z field.

The geometric dynamics of spacetime emerge in response to the correlation structure of the$Z$ field, giving rise to effective Einstein equations:

$$\left[G_{\mu\nu} = 8\pi G\left(T^{(m)}\mu\nu + T^{(Z)}\mu\nu\right)\right]$$

- ($G_{\mu\nu}$): Einstein tensor (spacetime curvature)
- ($T^{(m)}_{\mu\nu}$): matter energy-momentum tensor
- ($T^{(Z)}_{\mu\nu}$): Z-field tensor
- (G): gravitational constant

Gravity is an equation of state of the Z field. Relativistic geometry emerges from the correlations of the Z field. Gravity is an equation of state of the Z field, not a fundamental entity.

Starting from the covariant action:

$S = \int d^4\, x\sqrt{-g}\left[\frac{1}{16\backslash pi\, G} R \;+ \mathcal{L}_Z + \mathcal{L}_m\right]$

and varying with respect to the metric:
$\frac{\delta S}{\delta g_{\mu\nu}} = 0$
we obtain:

- geometric contribution → $G_{\mu\nu}$
- matter contribution → $T^{(m)}_{\mu\nu}$
- field contribution → $T^{(Z)}_{\mu\nu}$

These equations show that: Geometry emerges from the system's energy structure
In particular:

- matter and the field Z jointly contribute to the curvature
- gravity is not fundamental, but emergent

Gravity is the system's geometric response.
> Gravity as an emergent phenomenon

- it is not an independent fundamental interaction
- It arises from the dynamics of the field

> Equation of state
The field Z acts as:

- source of energy
- a generator of geometry

Gravity constitutes an equation of state of the field.
> Unification of components

- matter → $T^{(m)}_{\mu\nu}$
- correlations → $T^{(Z)}_{\mu\nu}$

both determine the geometry
> Physical regimes

- weak regime → recovery of general relativity
- strong regime → nonlinear corrections appear

Spacetime is not fundamental, but a consequence; equivalently, geometry is the macroscopic manifestation of correlations.
4.5 Newtonian limit

$$[\nabla^2 \Phi = 4\pi G \rho_{\text{eff}}]$$

Newtonian limit:

$$[\nabla^2 \Phi \sim (\nabla Z)^2 + V(Z)]$$

1. Action:

$S = \int \sqrt{-g} \left(\frac{R}{16\pi G} + \mathcal{L}_Z \right)$

2. Energy-momentum tensor:

$T_{\mu\nu}$

3. Weak limit:

$\nabla^2 \Phi = 4\pi G \rho_{\text{eff}}$

4. Then:

The effective energy density is dominated by the principal kinetic and potential contributions, given by:
$\rho_{\text{eff}} \sim (\nabla Z)^2 + V(Z)$

In the Newtonian limit, Poisson's equation is obtained from the effective energy-momentum tensor of the field$Z$, where the effective density is dominated by the kinetic and potential terms, yielding:

$$\nabla^2\Phi = 4\pi G\, \rho_{\text{eff}}(Z) \sim (\nabla Z)^2 + V(Z)$$

In the regime of weak fields and smooth variations, the effective behavior of the system can be compared to the Newtonian limit of gravity. In this context, the effective density associated with the emergent field (Z) is identified from its energy contribution.

Under these conditions, the dynamics lead to a Poisson-type equation:

$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}(Z)]$

where the effective density is dominated by terms of the form:

$[\rho_{\text{eff}}(Z) \sim (\nabla Z)^2 + V(Z)]$

This relation is not arbitrarily postulated, but rather emerges as an effective approximation when considering the contribution of the field (Z) to the energy content of the system in the regime:

$[|\nabla Z| \ll \Lambda^2]$

Classical limit (Newtonian type)

$\left[\nabla^2\Phi = \rho_{eff}(Z)\right]$

Effective Poisson equation: Connects the Z field with matter.

The relationship between the field$Z$ and the distribution of matter is established via a Poisson-type equation:

$$[\nabla^2 Z = 4\pi G\rho]$$

- ($\nabla^2 Z$): field curvature
- (ρ): matter density
- (G): gravitational constant

Matter generates deformations in Z. It connects the Z field with matter. Z acts as a gravitational potential.

This equation describes how matter generates deformations in the field.

In the regime of small variations:

- the equation of motion is linearized
- the field behaves like a classical scalar potential

Given that:

$Z \equiv \Phi$

and since in Newtonian gravity:

$\nabla^2\Phi = 4\pi G$

is obtained directly:

$\nabla^2 Z = 4\pi G$

The field Z responds to the presence of matter: matter curves the field Z

In this context:

- density acts as a source
- the field deforms in response
- gravity emerges from that deformation

> Field generation

- matter creates structure in Z
- defines the gravitational potential

> Propagation of gravitational effects

- Z variations are transmitted through space
- determine the acceleration of particles

> Consistency with classical physics

- exactly reproduces Poisson's equation

- ensures compatibility with Newtonian gravity

> Natural extension

Outside the linear regime:

- the equation changes
- nonlinear effects appear

Matter does not create a force, but rather induces structure in the field; equivalently, gravity is the field's response to matter.

Effective gravitational dynamics

The model predicts a modified effective acceleration of the form:
$[a(r) = a_N(r) + a_Z(r)]$
where:
$\left[a_N(r) = \frac{GM}{r^2}, \qquad a_Z(r) \text{ is the contribution of the countryside } Z\right]$
The effective energy density associated with the field is given by:
$[\rho_{\text{eff}}(Z) \sim (\nabla Z)^2 + V(Z)]$
This implies that the spatial gradients of the field contribute directly to gravitational dynamics, especially on large scales.

Poisson's equation and rotation curves

In the weak-field limit, the gravitational potential satisfies:
$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}(Z)]$
The rotation velocity is obtained from:
$$\left[\frac{v^2(r)}{r} = \frac{d\Phi}{dr} \quad \Rightarrow \quad v(r) = \sqrt{r, \frac{d\Phi}{dr}}\right]$$
Therefore, the rotation curves are determined by the radial profile of the field ($Z(r)$).

4.6 Gravitational potential

Identification with Newtonian Potential: Relationship between the field Z and the classical gravitational potential.

In the classical regime, the effective field Z is directly identified with the Newtonian gravitational potential:

$$[Z \equiv \Phi][\vec{a} = -\nabla\Phi = -\nabla Z]$$

- (Φ) = Newtonian gravitational potential
- (Z) = effective field
- ($\vec{a}$) = gravitational acceleration

The Z field acts directly as a gravitational potential in the classical limit.

In the limit of small gradients and weak dynamics:

- the field equation reduces to a linear form
- the field satisfies a Poisson-type equation

Since in classical gravity:

$\vec{a} = -\nabla$
and in the model:

$\vec{a} = -\nabla Z$
the direct identification is obtained:

$Z \equiv \Phi$
The field acts as the effective gravitational potential of the system; Z reproduces classical gravity in the appropriate limit.
In this framework:

- gravity emerges as a gradient of Z
- it is not necessary to introduce an additional potential
- the field dynamics contain the gravitational interaction

> Recovery of classical physics

- reproduces Newton's law
- ensures consistency with experimental observations

> Conceptual unification

- the gravitational potential is not independent
- it is a direct manifestation of the field Z

> Extension beyond the classical limit

- for large gradients → corrections appear
- the gravitational dynamics are modified

The gravitational potential corresponds to the Z field; in other words, classical gravity is a limit of the emergent field.

Gravitational acceleration: The gravitational force emerges as a gradient of the Z field.

In this framework, the gravitational force emerges as the spatial gradient of the field Z , directly defining the acceleration of a particle:

$$[\vec{a} = -\nabla Z]$$

- ($\vec{a}$): gravitational acceleration
- (∇Z): gradient of the effective field

Converts information variation → physical force. Gravity is not fundamental → it is the system's response to deviations from equilibrium.

Since the$Z$ field acts as the effective potential of the system:

- spatial variations generate forces
- particles respond by following the gradient

By analogy with classical mechanics:

$\vec{a} = -\nabla$

and using the ID:

$Z \equiv \Phi$

you get directly:

$\vec{a} = -\nabla Z$

Gravitational acceleration arises as the system's response to variations in the field:

information gradients $\Longrightarrow$ physical force

In this sense:

- there is no independent fundamental force
- dynamics emerge from the structure of the field
- the system tends to restore equilibrium

> Emergence of the force

- gravity appears as a collective effect
- It does not require any additional fundamental interaction

> Relationship with equilibrium

- regions with greater deviation → generate force
- the system evolves toward more stable states

> Unified interpretation

- information → gradient → acceleration
- coherence → equilibrium → stability

> Consistency with classical physics

- reproduces Newtonian dynamics
- allows extension to nonlinear regimes

La gravedad es una respuesta del sistema a desviaciones del equilibrio; de manera equivalente, la fuerza corresponde al gradiente de la información.

Emergent Gravitational Acceleration: Gravity is not fundamental; it is the gradient of the Z field.

Gravity is not fundamental; it is the gradient of the Z field.

In this framework, gravity is not considered a fundamental interaction, but rather an effective manifestation of the spatial variations of the$Z$ field. In particular, gravitational acceleration is identified with the gradient of the field:

$$[\vec{a} = -\nabla Z][\nabla^2 Z \approx 4\pi G\rho]$$

- ($\vec{a}$): gravitational acceleration
- (∇Z): field gradient
- (ρ): baryonic matter density
- (G): gravitational constant

Z acts as a Newtonian gravitational potential. In the limit of small gradients, Z acts as a Newtonian gravitational potential. Gravity is a force that restores equilibrium.

In the regime of small gradients:

$|\nabla Z|^2 \ll \Lambda^4$

the equation of motion reduces to a linear form:

$\nabla^2 Z \approx V'(Z)$

Identifying the effective potential with the matter density:

$V'(Z) \sim 4\pi G\rho$

we obtain:

$\nabla^2 Z \approx 4\pi G\rho$

which coincides with Poisson’s equation for Newtonian gravity.

The field acts as an effective gravitational potential:

$\boxed{Z \equiv \Phi_{\text{grav}}}$

In this sense:

- gravity emerges as a restoring force toward equilibrium
- masses generate gradients in Z
- bodies follow these variations as acceleration

> Recovery of Newtonian gravity

- in the weak limit, the model fully reproduces Newton’s law
- ensures consistency with classical observations

> Emergent interpretation

- Gravity is not fundamental
- it is a consequence of the field structure

> Role of matter

- ρ density acts as a source
- induces curvatures in Z

> Natural extension

Outside the linear regime:

- nonlinear corrections appear
- possible deviations from Newton

Gravity emerges as a restorative response to disturbances in systemic equilibrium, where the resulting force is equivalent to the gradient of information entropy

My equation:
$\frac{a}{1+a^2/\Lambda^4} = g_b$
yields:

- internal → dominated by mass
- exterior → dominated by nonlinearity

El sistema galáctico experimenta una transición en su régimen dinámico

5.7 Effective density

$$[\rho_{\text{eff}} \approx F'(X)|\nabla Z|^2 + V(Z)]$$

The vacuum as a quantum presence

Energy: Dynamic field energy.

The energy of the field Z is defined as the combination of dynamic and potential contributions, including nonlinear regulation effects:

$$\left[\rho_Z = \kappa \dot{Z}^2 + V(Z) - \zeta In\left(1 + \frac{\dot{Z}^2}{\Lambda^4}\right)\right]$$

- (ρ_Z): field energy density
- ($\dot{Z}$): time evolution of the field
- ($V(Z)$): potential energy
- (Λ): scale
- (κ): kinetic coefficient
- (ζ): intensity of the logarithmic term

Dynamic energy of the field. Describes the energy of the system.

The energy is constructed as the sum of three contributions:

1. **Kinetic term**

$\kappa \dot{Z}^2$

2. **Potential term**

$V(Z)$

3. **Logarithmic correction**

$\zeta In\left(1 + \frac{\dot{Z}^2}{\Lambda^4}\right)$

Field energy is a functional quantity that integrates its temporal evolution, its static equilibrium state, and its intrinsic regulatory mechanisms

In this framework:

- evolution generates dynamic energy
- potential determines the base state
- the log term controls extreme behaviors

Condition for the existence of the dynamic regime

The system must be outside the trivial homogeneous state, which implies:

$[\phi \neq 0, \quad \nabla Z \neq 0]$

This condition guarantees that:

- there is a deviation from equilibrium
- there is a spatial structure of the field
- the system exhibits non-trivial dynamics

> Background regime

When:

$\dot{Z} \approx 0$

→ the potential dominates

→ vacuum energy-like behavior

> Dynamic regime

When$\dot{Z} \neq 0$:

→ energy evolves

→ contributes to cosmological expansion

> Extreme regime

For large values of $\dot{Z}$:

→ the logarithm regulates growth

→ prevents divergences

> Global interpretation

- energy is not constant
- it depends on the dynamic state of the field

The energy of the universe is dynamic and self-regulating; equivalently, the field Z contains both the energy and its regulation.

4.8 Cosmological scale

$$[a_0 \sim cH_0]$$

Fundamental scale: Connects galaxies with cosmology.

A fundamental acceleration scale is introduced that directly links galactic dynamics with cosmological expansion:

$$[a_0 \sim cH_0]$$

- (a_0): characteristic acceleration scale
- (c): speed of light
- (H_0): expansion constant of the universe

The quantitycH_0 :

- has the dimensions of acceleration
- arises naturally from cosmological expansion

Since in the model the scalea_0 :

- controls the transition between dynamic regimes
- it appears in galactic dynamics

the following identification holds:

$a_0 \sim cH_0$

The evolution of galactic systems is linked to global dynamics, such that local structures reflect the influence of cosmological expansion on their kinematic behavior

In this sense:

- a_0 it is not an arbitrary parameter
- it is determined by the large-scale structure of the universe

> Multi-scale connection

- galactic phenomena ↔ cosmological expansion
- unification of physical scales

> Origin of MOND

- the scalea_0 is explained
- no empirical adjustment required

> Interpretation of the universe

- Expansion is not independent
- it influences local dynamics

> Strong prediction

- Changes inH_0 would imply changes in galactic dynamics
- establishes an observable relationship

The morphology and kinematics on the galactic scale are determined by the rate of the universe's expansion, establishing a fundamental link between the dynamics of local systems and the parameters of global cosmology

4.9 Cosmological Equations (Modified Friedmann)

The cosmological evolution of the universe is described by a modified Friedmann equation, in which the (Z) field dynamically contributes to expansion through an effective density.

This formulation extends the standard cosmological framework by incorporating an additional dynamic component associated with the field, while maintaining consistency with the evolution of the background in relativistic cosmology. Friedmann's cosmological solutions describe the expansion of the universe under geometric assumptions. In this work, this expansion is interpreted as the global evolution of the correlation state of the field Z, (Friedmann, 1922).

Modified Friedmann Equation: Cosmological evolution of the background with a contribution from the Z field.

The cosmological evolution of the universe is described by a modified Friedmann equation, in which the Z field dynamically contributes to the expansion through an effective density.

$$\left[H^2 = \frac{8\pi G}{3}(\rho_m + \rho_Z)\right]\left[\rho_Z = \kappa\dot{Z}^2 + \zeta\left(1 + \frac{\dot{Z}^2}{\Lambda^4}\right) + V(Z)\right]$$

- (H): Hubble rate
- (ρ_m): matter density
- (ρ_Z): effective field density
- ($\dot{Z}$): time evolution of the field
- (κ): kinetic parameter
- (ζ): intensity of the logarithmic term
- (Λ): fundamental scale
- ($V(Z)$): potential

Z participates in expansion. Expansion of the universe; in the background, ($\rho_Z \approx V(Z)$).

The$Z$ field contributes to the total energy through:

- kinetic term → $\kappa\dot{Z}^2$
- nonlinear correction → logarithmic term
- potential → $V(Z)$

This modifies the standard Friedmann equation by including an additional dynamic component.

The Z field actively participates in the expansion; the expansion of the universe includes dynamic contributions from this field.

In the cosmological background:

$\dot{Z} \approx 0 \Rightarrow \rho_Z \approx V(Z)$

> Emerging dark energy

- $V(Z)$ dominates on large scales
- generates accelerated expansion

> Nonlinear dynamics

- the log term introduces corrections
- modifies evolution in intermediate regimes

> Cosmological unification

- matter + field Z describe the entire expansion
- no external components are required

> Background regime

- the field approaches equilibrium
- the effective energy stabilizes

The expansion of the universe is governed by the dynamics of the field Z ; equivalently, dark energy corresponds to the potential of the field at equilibrium.

4.10 Effective (logarithmic) corrections

Emergent gravity and logarithmic regularization

Gravity is not introduced as a fundamental force, but as the manifestation of the emergent geometry associated with the organization of correlations of the field (Z) .

The deviations ($\phi = Z - 0.5$) and the gradients (∇Z) connect scales: at the microscopic level they describe correlations, while at the macroscopic level they translate into geometric curvature, in accordance with general relativity. General relativity establishes that gravity is a geometric manifestation of spacetime. In the present framework, this geometry is not posited as fundamental, but rather emerges from the dynamics of the field$Z$, reinterpreting curvature as a collective response of the system's correlations. (Einstein, 1915).

An effective logarithmic term is incorporated that modulates the dynamics in high-curvature regimes, smoothing the growth of geometric invariants and acting as a regularization mechanism. This term can be represented schematically as $(R + \alpha \ln \mathrm{R})$, where (R) denotes a geometric invariant.

This term is not interpreted as an independent fundamental law, but rather as an effective correction that prevents divergences and captures relevant effects in extreme domains, including the possible regularization of singularities in classical descriptions.

From this perspective, gravitational curvature does not correspond to a fundamental deceleration of expansion, but rather to the way in which the system's configurations modify the local geometry. High-density regions induce a distinct metric structure, manifesting as curved trajectories and time dilation.

Thus, gravity is interpreted as the geometric expression of the organization of correlations in the field (Z) , while the logarithmic corrections capture relevant deviations in extreme regimes and establish an effective bridge between the classical description and quantum effects.

Physical interpretation

The logarithmic term encodes the redistribution of correlations across scales. Unlike power-law scaling, logarithmic behavior implies:

$$[lnR \leq R\alpha]$$

which leads to a natural regularization of high-curvature behavior. From this perspective, the effective gravitational dynamics preserves information about the coarse-grained microscopic structure of the system.

4.11 Emergence of the metric

In general relativity, the metric ($g_{\mu\nu}$) is a dynamic entity determined by the system's energy and momentum. Within the framework of the field (Z) , this description is extended: the metric is not fundamental, but rather an effective structure that emerges from the organization of the deviations ($\phi = Z - 0.5$) and their gradients (∇Z) .

Spacetime does not constitute a preexisting background, but rather appears only when the system admits distinguishable configurations and coherent correlations that allow for the definition of distances, scales, and causality. In this context, gravity does not act on a given geometry, but rather forms part of the process through which the correlations of the field acquire geometric structure.

Thus, while general relativity takes geometry as fundamental, this model interprets it as an emergent consequence of the underlying dynamics of the field (Z) .

The emerging metric depends on the distribution of correlations and field gradients, giving rise to non-uniform dynamics in the system. In low-density regions, where deviations are small and correlations are weak, global expansion dominates, increasing effective distances. In high-density regions with intense gradients, stable configurations modify the local metric, generating curvature and time dilation.

These regimes do not represent a fundamental duality, but rather distinct scales of organization that coexist dynamically. The equilibrium around ($Z = 0.5$) allows for compatibility between global expansion and the persistence of local structures, reflecting a hierarchical organization of the field correlations.

In this framework, the ($g_{\mu\nu}$) metric describes the macroscopic behavior of the system, while the (Z) scalar field constitutes the fundamental degree of freedom. Its dynamics determine the effective energy content through an energy–momentum tensor ($T_{\mu\nu}(Z)$) , from which geometry emerges as a response, in analogy with Einstein's formalism (Einstein, 1915).

The value ($Z = 0.5$) defines a homogeneous reference state characterized by the absence of gradients ($\nabla Z = 0$) , in which the energy contribution is minimal and the geometry is approximately flat. Deviations ($\phi = Z - 0.5$) generate spatial and temporal gradients that induce an effective energy density, acting as a source of curvature and giving rise to a non-trivial geometry.

Thus, gravity is not introduced as an independent fundamental interaction, but rather as an emergent phenomenon resulting from the dynamics of the field (Z) , maintaining the separation between geometry and energy content characteristic of the relativistic formalism. This allows additional gravitational effects to be interpreted as manifestations of the field structure, without requiring additional material components.

Gravity can be understood as the manifestation of configurations in which field correlations are intense and highly organized. In high-density regions, with significant (ϕ) deviations and gradients, stable structures form that modify the emergent metric.

This concentration induces geometric curvature, in accordance with general relativity, and manifests as curved trajectories and time dilation. Global expansion and local gravity are not opposing processes, but complementary regimes: the former describes large-scale evolution, while the latter reflects structural persistence at the local level.

Thus, gravity expresses how field configurations reorganize the relational structure of the system, allowing for the coexistence of expansion and stability.

- $\left(T_{\mu\nu}\right)$-induced geometry
- dependence on gradients

Effective form of gravity

$\left[G_{\mu\nu} = f(Z, \nabla Z)\right]$

equivalently:

$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}^{\text{eff}}(Z)\right]$

with:

$\left[T_{\mu\nu}^{\text{eff}} \sim \nabla_\mu Z \nabla_\nu Z + g_{\mu\nu} V(Z)\right]$

This effective energy curves spacetime.

Spacetime is not a "Background"; it is the "Result of the Emerging Structure"

In General Relativity, the metric $g_{\mu\nu}$ is a dynamic entity determined by the energy and momentum of the system.

Within the framework of the field Z , this description extends: the metric is not fundamental, but rather an effective structure that emerges from the organization of the deviations $\phi = Z - 0.5$ and their gradients ∇Z .

Spacetime does not constitute a pre-existing background, but rather appears only when the system admits distinguishable configurations and coherent correlations that allow for the definition of distances, scales, and causality.

In this context, gravity does not act on a given geometry, but rather forms part of the process through which the correlations of the field acquire geometric structure.

Thus, while General Relativity takes geometry as fundamental, this model interprets it as an emergent consequence of the underlying dynamics of the field Z .

Variation of the Metric and System Dynamics

The emergent metric depends on the distribution of correlations and gradients of the Z field, giving rise to non-uniform dynamics of the system.

1. Low-density regions: When deviations are small and correlations weak, global expansion dominates, increasing the effective distances between regions.
2. High-density regions: In the presence of intense gradients, stable configurations modify the local metric, generating gravitational effects such as curvature and time dilation.

These regimes do not represent a fundamental duality, but rather distinct scales of system organization that coexist dynamically.

The equilibrium around $Z = 0.5$ allows for compatibility between global expansion and the persistence of local structures, reflecting a hierarchical organization of field correlations.

>Status of the metric and the emergent nature of gravity

In this framework, the metric $\left(g_{\mu\nu}\right)$ is not interpreted as a fundamental entity, but rather as an effective geometric structure that describes the macroscopic behavior of the system.

The scalar field (Z) constitutes the fundamental degree of freedom, whose dynamics determine the effective energy content through the energy–momentum tensor ($T_{\mu\nu}(Z)$). The geometry of spacetime is not imposed a priori, but rather emerges in response to this energy distribution, in a manner analogous to the formalism of Einstein’s equations.

In particular, the value ($Z = 0.5$) defines a homogeneous reference state characterized by the absence of gradients:

$\left[\nabla_\mu Z = 0\right]$

In this regime, the field’s energy contribution is minimal and the geometry is approximately flat.

Deviations from this value, described by ($\phi = Z - 0.5$), generate spatial and temporal gradients that induce an effective energy density:

$[\rho_{\text{eff}} \sim |\nabla Z|^2 + V(Z)]$

These contributions act as a source of curvature, giving rise to a non-trivial geometry at the macroscopic level.

Thus, gravity is not introduced as an independent fundamental interaction, but rather as an emergent phenomenon resulting from the dynamics of the field (Z), maintaining the separation between geometry and energy content characteristic of the relativistic formalism.

This formulation allows us to interpret the additional gravitational effects as manifestations of the field structure, without requiring the introduction of additional material components.

Gravity as the structural persistence of correlations

Gravity is not introduced as a fundamental force, but as the manifestation of configurations where the correlations of the Z field are intense and highly organized.

In high-density regions, with significant deviations $\phi = Z - 0.5$ and gradients ∇Z , stable structures form that modify the emerging metric, reflecting the persistence of these correlations.

This concentration induces geometric curvature, in accordance with General Relativity, and manifests as curved trajectories and time dilation.

Global expansion and local gravity are not opposing processes, but complementary regimes: the former describes large-scale evolution, while the latter reflects structural stability at the local level.

Thus, gravity expresses how field configurations reorganize the relational structure of the system, allowing for the coexistence of expansion and stability.

Metric–Correlation Relationship: Functional relationship between the spacetime metric and field correlations.

A functional relationship is established in which the spacetime metric emerges directly from the correlation structure of the field Z .

$$\left[g_{\mu\nu}(x) \sim \partial_\mu \partial_\nu \ln \mathcal{C}\,(x_1, x_2)\right]$$

- ($\mathcal{C}(x_1, x_2)$): correlation function of the field
- ($g_{\mu\nu}$): effective spacetime metric

The geometry emerges directly from the correlation structure of the Z field.

Starting from:

$$\mathcal{C}(x_1, x_2) = \langle Z(x_1) Z(x_2) \rangle$$

geometry is constructed from:

- the spatial variation of the correlations
- the curvature induced by changes in coherence

The second derivative of the logarithm captures:

- local changes in connectivity
- the effective structure of the metric

Geometry is not fundamental; the metric is a manifestation of the correlations.
In this framework:

- highly correlated regions → “flat” geometry
- variations in correlation → curvature

> Emergent geometry

- spacetime arises from the field
- it is not an independent entity

> Curvature as information

- Curvature reflects changes in correlation
- connects geometry with information

> Conceptual unification

- Z field → correlations
- correlations → metric
- metric → gravity

> Basis for emergent gravity

- allows for the derivation of gravitational equations
- without postulating fundamental geometry

The geometry of spacetime is a function of the system’s coherence; equivalently, curvature corresponds to the variation in correlations.

Emergent Metric from Z Correlations: The geometric distance emerges from the correlations of the Z field.

The geometric distance between two points is not fundamental, but rather emerges from the correlations of the Z field, which encode the coherence of the system.

$$\left[d(x_1, x_2)^2 \sim \frac{1}{\mathcal{C}(x_1, x_2)}\right] [\mathcal{C}(x_1, x_2) = \langle Z(x_1) Z(x_2) \rangle]$$

- ($d(x_1, x_2)$): effective distance
- ($\mathcal{C}(x_1, x_2)$): correlation function
- ($Z(x)$): field

Space is a network of coherence. High correlation → small distance; low correlation → large distance. Two regions "are close" to the extent that they are correlated.

The following correspondence is postulated:
distancia $\sim \frac{1}{\text{correlación}}$

Given that:

- correlations measure coherence
- coherence defines connectivity

then geometry emerges as a network of correlations.

Distance is an emergent property; proximity corresponds to correlation.

In this framework:

- high correlation → small distance
- low correlation → large distance

> Space as a network

- space is not fundamentally continuous
- it is a network of coherence

> Emergent geometry

- The metric arises from correlations
- It is not imposed from the outside

> Physical connectivity

- correlated regions are “close”
- uncorrelated regions are “far away”

> Relationship with entanglement

- correlation ↔ entanglement
- connects geometry with information

Space is a structure of correlations; equivalently, geometry emerges from the coherence of the field Z .

4.12 Recovery of General Relativity

Unification with General Relativity

General relativity describes the dynamics of the metric in terms of energy and momentum, but does not specify the fundamental origin of geometry. In this framework, the metric is interpreted as a structure emerging from an underlying dynamic.

In the field model (Z) , geometry emerges as an effective description of collective configurations, while Einstein’s equations are recovered as a macroscopic approximation valid in regimes of smooth geometry (Einstein, 1915).

Thus, general relativity is not replaced, but rather emerges as an effective theory. Relativistic time is likewise interpreted as an emergent property associated with the metric, and not as a fundamental parameter.

The unification is organized hierarchically: at the fundamental level, the dynamics of the system are described by the field (Z) ; at the effective level, the metric and the validity of general relativity emerge.

In this way, general relativity is interpreted as a macroscopic manifestation of a deeper structure in which geometry is not fundamental, but emergent.

1. Geometry emerges as an effective description of collective configurations.
2. Einstein's equations are recovered as a valid macroscopic approximation in regimes of smooth geometry.

Thus, general relativity is not replaced, but rather emerges as an effective theory.

Relativistic time is also understood as an emergent property associated with the metric, and not as a fundamental parameter.

The unification is organized hierarchically:

1. Fundamental level: dynamics of the system described by Z.
2. Effective level: emergence of the metric and validity of general relativity.

Thus, general relativity is interpreted as a macroscopic manifestation of a deeper structure in which geometry is not fundamental, but emergent.

4.13 Fundamental Scale of the Model

Identification of Fundamental Scales: Relationship between the model parameters and the fundamental physical scales.

The relationship between the characteristic scale of the field Z and the fundamental gravitational scale is established, identifying both as being of the same order:

$$[\Lambda \sim M_P]$$

- (M_P) = Planck mass
- (Λ) = field coherence scale

The coherence scale of the Z field is directly related to the fundamental gravitational scale.

TheΛ scale controls:

- the transition between linear and nonlinear regimes
- the intensity of the regulation effects

On the other hand, the Planck mass M_P :

- sets the scale of gravity
- determines the magnitude of G

Since the field Z reproduces gravitational dynamics, it is natural to identify both scales:

$\Lambda \sim M_P$

The coherence scale of the field coincides with the gravitational scale: The structure of the field is anchored to the Planck scale

This implies that:

- the dynamics of the field and gravity have a common origin
- there is no separation between microstructure and gravity

> **Unification of scales**

- a single scale governs the entire system
- it eliminates redundancies in the theory

> **Consistency with gravity**

- ensures that the model correctly reproduces
- connects directly to general relativity

> **Interpretation of the field**

- Z is not arbitrary

- is determined by the fundamental structure of spacetime

> Strong prediction

- any deviation from Λ would imply new physics
- the scale of the model is constrained

The coherence of the field and gravity share the same scale
or equivalently:

$\Lambda \sim M_P \Rightarrow$The magnitude of the coupling constant, on the order of the Planck scale. implies the existence of a single fundamental parameter that governs the overall structure of the theory

Fundamental Scale Normalization: Fixing the model constants in terms of fundamental physical units.

The normalization of the model constants is established by fixing the scales in terms of fundamental physical units, in particular the Planck mass:

$$\left[G = \frac{1}{M_P^2}, \quad \Lambda \sim M_P\right]$$

- (M_P) = Planck mass
- (G) = gravitational constant
- (Λ) = fundamental field scale

The Z-field scale is anchored to the gravitational scale, eliminating ambiguities in the parameterization.

In natural units $c = \hbar = 1$:

- Newton's constant defines the gravitational scale
- the Planck mass is introduced as:

$M_P = \frac{1}{\sqrt{G}}$

Since in the model Λ controls:

- the transition between regimes
- the intensity of nonlinear effects

the following identification is established:

$\Lambda \sim M_P$

eliminating redundant degrees of freedom in the parameterization.

The scale of the Z field is anchored to the gravitational scale: The dynamics of the field are determined by the Planck scale

In this sense:

- there is no ambiguity in the model's scale
- gravity and the field share the same origin

> Elimination of arbitrariness

- Λ it ceases to be free
- the model is completely normalized

> Dimensional consistency

- all quantities are well-defined
- the model is physically consistent

> Unification of scales

- Field microstructure ↔ gravity
- A single scale governs the system

> Fundamental interpretation

- the coherence scale coincides with the gravitational scale
- the field structure is directly linked to the geometry

The field scale and the gravitational scale are the same

or equivalently:

$\Lambda \sim M_P \Rightarrow$a single fundamental scale

Derived Newtonian Constant: G emerges from the coherence scale Λ.

In this framework, the gravitational constant G is not an arbitrary fundamental parameter, but rather emerges from the system's coherence scale, characterized by Λ:

$$\left[G \sim \frac{1}{M_P^2}, \quad M_P \sim \Lambda\right]$$

- (G): gravitational constant
- (M_P): effective Planck mass
- (Λ): coherence scale of the system

It measures the informational compression capacity of the vacuum. The gravitational constant is not arbitrary.

In gravitational theories, Newton's constant is related to the Planck scale:

$G \sim \frac{1}{M_P^2}$

In this model, the fundamental scale of the system is determined by Λ, which sets:

- the transition between regimes
- the intensity of correlations

Identifying:

$M_P \sim \Lambda$

we directly obtain:

$G \sim \frac{1}{\Lambda^2}$

The gravitational constant measures a property of the system: the informational compression capacity of the vacuum.

In this sense:

- it is not fundamental
- it depends on the structure of the field
- it reflects how easily correlations are generated

> Non-arbitrary origin of G

- it is not a free parameter
- emerges from the scale of the system

> Relationship with gravity

- higher $\Lambda \rightarrow$ lower G
- smaller $\Lambda \rightarrow$ larger G

> Interpretation of the vacuum

- the vacuum has structure
- its ability to organize information determines gravity

> Fundamental scale

- determines the system's overall behavior
- connects microstructure with macroscopic gravity

Gravity is determined by the structure of the vacuum; equivalently, $\boldsymbol{G}$ measures how compressible the information of the universe is.

5. Phenomenology and Effective Dark Matter

5.1 Quantum Field Limit

Quantum limit of the field - Schrödinger: Quantum limit of Z .

The Schrödinger equation describes the quantum limit of the Z field, where its effective dynamics is represented by a wave function.

In the quantum regime, the field acquires a wave-like structure described by a decomposition into amplitude and phase.

$$\left[i\hbar\, \partial_t \psi = -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi\right]$$

- (ψ): wave function
- ($\hbar$): reduced Planck constant
- (m): effective mass
- (V): potential

In the regime:

$X \ll \Lambda^4$

- the field behaves linearly
- it can be represented in terms of amplitude and phase

This allows its dynamics to be described by an evolution equation forψ .

The equation describes the quantum evolution of the system; the wave function constitutes an effective description of the field Z .

In this framework:

- $|\psi|^2$represents the probability density
- the potential governs the dynamics

> **Quantum limit**

- quantum behavior emerges from the field
- it is not fundamental, but effective

> **Wave dynamics**

- evolution over time
- spatial propagation

> **Interpretation of the system**

- the underlying field is described as a wave function
- connects classical theory with quantum mechanics

Quantum mechanics is the effective limit of the field-Z ; equivalently, the wave function emerges from the dynamics of the field.

5.2 Phase Representation

Quantum limit: quantum phase.

$$\left[Z = Ae^{iS/\hbar}\right]$$

- (Z): field
- (A): amplitude
- (S): phase (action)
- ($\hbar$): reduced Planck constant

QM emerges from Z: wave structure

At the limit:

$|\nabla Z|^2 \ll \Lambda^4$

- the field behaves linearly
- it admits a complex representation

This introduces a dynamic phase that governs the evolution.

The structure of the field is wave-like: The phase encodes the quantum dynamics

In this framework:

- A it determines the amplitude
- S determines the evolution

> Quantum emergence

- quantum mechanics emerges from the field
- it is not fundamental

> Wave nature

- interference and superposition appear
- typical quantum behavior

> Classical–quantum connection

- S connects with classical action
- bridge between both regimes

Quantum mechanics corresponds to the phase structure of the field Z ; equivalently, the wave function emerges from the dynamics of the field.

5.3 Quantum Effective Action.

Quantum Effective Action (Limit): Effective description of the Z field in the quantum regime via a phase expansion.

In the regime of small gradients, the field admits a representation in terms of amplitude and phase that defines a quantum effective action.

$$\left[Z(x,t) = A(x,t)e^{iS/\hbar}\right]$$

(A) = amplitude

(S) = effective action

It allows the effective quantum dynamics to be derived as a limit of the continuous model.

This decomposition allows us to describe the dynamics of the field in terms of a phase that acts as an effective action, connecting the continuous model with its quantum limit.

Quantum dynamics emerges as a phase representation of the Z field.

5.4 Effective Derivation of Schrödinger

Emergence of the Schrödinger Equation: In the small-gradient limit, Z satisfies a Klein–Gordon-type equation that factors into the Schrödinger equation

In the limit of small gradients, the field satisfies a Klein–Gordon-type equation which, through a decomposition into amplitude and phase, reduces to an effective Schrödinger equation.

$$\left[Z(x,t) = A(x,t), e^{iS/\hbar}\right]\left[i\hbar, \partial_t \psi = -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi\right]$$

- (Z): effective field
- ($A(x,t)$): amplitude
- ($S(x,t)$): phase
- ($\hbar$): reduced Planck constant
- (ψ): wave function
- (m): effective mass
- (V): potential

Quantum mechanics emerges as an effective limit of the Z field in the weak regime; it factors into the Schrödinger equation. The quantum potential arises from the logarithmic term.

In the regime:
$X \ll \Lambda^4$

- the Lagrangian is linearized
- the equation of motion approximates a Klein–Gordon-type form

Applying the decomposition:
$Z = A\, e^{iS/\hbar}$

the following are separated:

- phase equation → Hamilton–Jacobi-type dynamics
- amplitude equation → conservation

Combining both yields an effective equation:
$i\hbar\partial_t\psi = -\frac{\hbar^2}{2m}\nabla^2\psi + V$

Quantum mechanics emerges as an effective limit of the field; the wave function constitutes a representation of the field Z .

In this framework:

- → probability density
- → dynamic phase

> Quantum limit

- quantum behavior arises in the weak regime
- it is not fundamental, but emergent

> Origin of the quantum potential

- the logarithmic term introduces corrections
- generates a quantum potential-like structure

> Interpretation of ψ

- is not fundamental
- describes an approximation of the field

> Conceptual unification

- classical field → Z
- quantum limit →ψ

Quantum mechanics is an effective regime of the fundamental field; equivalently, the wave function emerges from the structure of the Z field.

5.5 Decoherence and quantum-classical transition

Effective decoherence without an external observer

In this framework, decoherence does not require an external observer or a fundamental collapse mechanism. It is understood as an emergent process associated with the dynamics of the (Z) field, in which quantum correlations are redistributed through the interaction between different degrees of freedom.

When the system exhibits deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) , quantum configurations couple to the effective environment defined by other excitations of the field itself. This coupling generates entanglement with an increasing number of degrees of freedom, leading to the loss of coherence observable in local subsystems.

The “collapse” of the wave function is not interpreted as a fundamental process, but rather as an effective description of this loss of coherence. Superpositions do not disappear globally, but they cease to be accessible locally due to the dispersion of information within the system.

In this sense, the dynamics of the field (Z) provide the framework in which decoherence occurs naturally, without the need to introduce a privileged observer. Classical behavior emerges when quantum correlations become practically irreversible on the macroscopic scale.

This interpretation is compatible with standard approaches to decoherence, in which the loss of coherence is associated with interaction with the environment (Zurek, 2003), although here it is understood as a direct consequence of the system's dynamic organization. The decoherence process, developed by Zurek, describes the transition from quantum to classical behavior through the loss of coherence in correlations. In the present model, this process is identified with the evolution of the field$Z$, providing a dynamic basis for the emergence of classicity.

Decoherence as a Progressive Process

The transition from quantum superpositions to classical behavior is not an instantaneous collapse, but a progressive process of decoherence.

In the field (Z) , the evolution characterized by deviations ($\phi = Z - 0.5$) and gradients (∇Z) determines the organization of correlations and the increase in entanglement, causing quantum interference to gradually become unobservable at the local level.

Cosmological expansion influences this process by modifying the global structure of correlations, without acting as a direct cause of decoherence.

Thus, the loss of coherence corresponds to a gradual transition in which superpositions cease to be accessible, and classical behavior emerges as an effective description of stable configurations in the face of decoherence.

5.6 Consistency with Standard Quantum Mechanics and Connection to Decoherence

A fundamental requirement of any emergent model is the recovery of standard quantum mechanics in the appropriate regime. In the present framework, this corresponds to the high-coherence limit of the system, characterized by:

$$\left[X = \nabla_\mu Z \nabla^\mu Z \ll \Lambda^4\right]$$

where the nonlinear effects associated with the logarithmic term in the Lagrangian are negligible. In this regime, the field dynamics reduces to:

$$[\mathcal{L} \approx X - V(Z)]$$

which corresponds to a standard scalar field. Consequently, the equation of motion takes the linear form:

$$[\Box Z + V'(Z) = 0]$$

ensuring compatibility with quantum field theory in the perturbative limit.

In this context, the effective Planck constant satisfies:

$$[\hbar_{\text{eff}}(X) \approx \hbar_0]$$

thus restoring the standard commutation relations:

$$\left[[x,p] = i\hbar_0\right]$$

and, consequently, Heisenberg's uncertainty relation:

$$\left[\Delta x, \Delta p \geq \frac{\hbar_0}{2}\right]$$

This demonstrates that conventional quantum mechanics emerges as an effective regime of the model under conditions of high coherence, ensuring consistency with well-established experimental results.

Dynamic transition and decoherence:

Outside the regime $(X \ll \Lambda^4)$, , the logarithmic term in the Lagrangian introduces a nonlinear dynamics that modifies the effective field flow:

$$\left[J^\mu = \frac{\nabla^\mu Z}{1 + \frac{X}{\Lambda^4}}\right]$$

This structure implies an effective reduction in coherent propagation for large gradients, which can be interpreted as an intrinsic mechanism of decoherence.

In the standard formulation of decoherence (Zurek, 2003), the loss of quantum coherence arises from the interaction between a system and its environmental degrees of freedom, leading to the suppression of interference terms in the density matrix:

$\left[\rho(x,x') \to \rho(x,x'), e^{-\Gamma(x-x')}\right]$

where (Γ) quantifies the decoherence rate.

In the present model, this behavior emerges dynamically from the dependence of ($\hbar_{\text{eff}}$) on the kinetic invariant:

$$\left[\hbar_{\text{eff}}(X) = \hbar_0 \frac{1}{1+\frac{X}{\Lambda^4}}\right]$$

As(X) increases, the effective Planck constant is suppressed:

$[X \gg \Lambda^4 \quad \Rightarrow \quad \hbar_{\text{eff}} \to 0]$

which implies a progressive reduction of quantum effects and the disappearance of interference. In this sense, decoherence does not require an explicit external environment, but rather arises as an intrinsic property of the field dynamics.

Physical interpretation

From this perspective, three dynamic regimes can be identified:

Coherent quantum regime $\left((X \ll \Lambda^4)\right)$:
$[\hbar_{\text{eff}} \approx \hbar_0,]$
the dynamics are linear and standard quantum mechanics is recovered.

Intermediate regime:
the dependence on ($\hbar_{\text{eff}}$) introduces a gradual transition, in which quantum and classical effects coexist.

Classical regime:

$\left((X \gg \Lambda^4)\right)$: $[\hbar_{\text{eff}} \to 0]$
the dynamics effectively become classical, and quantum interference is suppressed.

In this framework, the quantum-classical transition is not an external or ad hoc process, but a direct consequence of the system's evolution in the configuration space of the field.

Finally, this description is consistent with the modern framework of decoherence, in which the classical emerges from the loss of quantum coherence. However, the present model extends this interpretation by proposing that such a loss of coherence is governed by the internal dynamics of the field and not exclusively by interaction with an external environment.

Taken together, quantum mechanics is interpreted as an effective regime of high coherence, while classical behavior emerges dynamically from the suppression of ($\hbar_{\text{eff}}$) , providing a unified framework to describe both limits within a single theory.

5.7 Decoherence Framework

The (Z) field does not act as an agent of collapse, but rather as the dynamic environment in which decoherence emerges naturally.

When there are deviations from ($\phi = Z - 0.5$) and finite gradients (∇Z) , quantum configurations couple across multiple degrees of freedom, generating entanglement and redistribution of correlations.

This process leads to the loss of coherence observable in local subsystems, while superpositions persist at the global level. The "collapse" of the wave function is interpreted as an effective description of the inaccessibility of information.

The metric structure and global dynamics of the system determine the scales of decoherence by regulating the organization of correlations and the dispersion of entanglement.

In this context, the transition to classical behavior arises from the system's internal dynamics, without eliminating the probabilistic nature of quantum theory.

5.8 Evolution of decoherence

The early regimes of the system are characterized by high quantum coherence, low correlation complexity, and the absence of a well-defined metric, allowing for extended superpositions.

As deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) emerge, the coupling between degrees of freedom and the complexity of correlations increase, intensifying decoherence processes.

The transition to classical behavior does not imply a fundamental selection, but rather the loss of observable coherence in local subsystems.

Thus, macroscopic structure emerges when decoherence becomes dominant, favoring stable configurations over the system's dynamics.

Cosmological expansion can be interpreted as a process of progressive decoherence that transforms highly correlated states into classical macroscopic configurations.

Cosmological expansion can be reinterpreted as an effective decoherence process. In previous work, it was proposed that cosmological expansion can be interpreted as a global decoherence process (Perez Cortes 2026a); this mechanism extends the previously proposed framework in which the expansion of the universe acts as a unifying element between relativity and quantum mechanics.

In the present model, this idea follows naturally: the expansion corresponds to the evolution of the correlational state of the field Z , in which the loss of coherence on a large scale induces an effective behavior compatible with the Friedmann cosmological solutions and with the observations of the cosmic microwave background measured by Planck.

5.9 Primordial decoherence

Primordial decoherence is neither a singular event nor a fundamental collapse, but rather the onset of a dynamic regime in which the system admits distinguishable configurations.

In the early states, the system exhibits high quantum coherence and the absence of an effective metric, with no geometric or temporal distinction.

The emergence of deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) allows us to define relationships between configurations, introducing effective degrees of freedom and a geometric structure.

From this point on, decoherence emerges as a redistribution of correlations through coupling between degrees of freedom, generating a loss of coherence observable at the local level.

Initial irregularities act as seeds of structure, allowing evolution toward stable macroscopic configurations.

Thus, matter and cosmological structure result from the transition from a highly coherent regime to one in which the metric, correlations, and decoherence coexist in an organized manner.

5.10 Intrinsic Decoherence

Intrinsic decoherence of the universe

Decoherence does not require an external observer: in the field (Z) , the set of degrees of freedom itself acts as an effective environment through coupling and entanglement.

When there are ($\phi = Z - 0.5$) deviations and finite (∇Z) gradients, configurations become distinguishable and subsystems redistribute their correlations, generating a loss of coherence observable at the local level.

This process is intrinsic to the system's dynamics and does not involve a fundamental measurement mechanism. Classical behavior emerges when quantum correlations are dispersed among a large number of degrees of freedom.

Stable configurations are those that persist in the face of this decoherence, while superpositions become inaccessible.

In this context, time describes the order in which these correlations reorganize, reflecting the transition from quantum regimes to classical behavior.

5.11 Decoherence and Gravity

Coherence and decoherence in the presence of gravity

Gravity can be interpreted as the manifestation of regions with intense correlations of the field (Z) , where the deviations ($\phi = Z - 0.5$) and the gradients (∇Z) modify the emerging metric.

In high-density regions, local dynamics favor the persistence of correlations, which alters the scales of decoherence without halting it.

Within the framework of general relativity, these regions correspond to intense curvatures of the metric, where proper time dilates as a function of the local geometric structure (Einstein, 1915).

In the case of black holes, this effect reaches an extreme regime: processes near the event horizon appear strongly slowed down from the outside, reflecting the modification of the system's dynamics under limiting conditions.

Thus, gravity does not preserve a fixed state, but rather regulates the evolution of correlations, affecting decoherence, structure, and the rhythm of time across different regimes.

5.12 Cosmological decoherence

Classical matter emerges when the system admits a stable relational structure, which requires deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) .

The emergence of an effective metric allows us to distinguish configurations and establish relationships, introducing a temporal order and enabling decoherence processes.

Decoherence is interpreted as the redistribution of quantum correlations through coupling between degrees of freedom, which renders superpositions inaccessible at the local level and gives rise to classical behavior.

The emergence of structure can be summarized as: metric → temporal order → decoherence → macroscopic structure.

These processes are not linear but interdependent, forming a common dynamic regime that includes geometry, time, expansion, and decoherence.

Thus, the quantum–classical transition emerges from the system's internal dynamics, without requiring external observers, and is governed by stability around a ($Z = 0.5$) .

5.13 Coherence and the quantum–classical transition

COHERENCE AND DECOHERENCE

Quantum mechanics describes the correlation structure of the system in a regime where the geometry is not yet effectively defined.

In the absence of ($\phi = Z - 0.5$) deviations and finite (∇Z) gradients, neither a metric nor an operational notion of time can be established, but a description in terms of quantum states and coherence can.

Geometry and time emerge when the system admits distinguishable configurations, allowing spatial and temporal relations to be defined. In this context, quantum evolution does not require a fundamental time, but rather an effective parameterization of change associated with the dynamic organization of correlations.

Thus, quantum mechanics can be interpreted as a description of the system in a regime prior to the emergence of geometry.

Local coherence and decoherence in field dynamics (Z)

dynamics exhibits different regimes depending on the distribution of its correlations.

In low-density regions, with weak correlations and small (∇Z) gradients, global dynamics dominate and the metric reflects large-scale expansion. In high-density regions, with organized ($\phi = Z - 0.5$) deviations and intense correlations, stable configurations form that modify the local metric, giving rise to gravitational structures.

In this context, local decoherence describes the redistribution of correlations: dispersion in sparse regions and organization in dense regions. The global behavior of the system results from the coexistence of both regimes expansion and gravitational structuring whose equilibrium is determined by the stability around ($Z = 0.5$) .

Unifying Principle of Coherence and Decoherence

Coherence and decoherence are complementary aspects of the dynamics of the (Z) field, and not independent processes.

In regimes without a defined metric structure, the system exhibits high coherence, with simple correlations and extended superpositions. The emergence of ($\phi = Z - 0.5$) deviations and finite (∇Z) gradients introduces a relational structure, allowing for the definition of distances, scales, and a temporal order.

As the coupling between degrees of freedom increases, correlations are redistributed through entanglement, leading to effective decoherence in local subsystems. The quantum–classical transition thus corresponds to a regime change in which decoherence dominates at certain scales, favoring stable configurations.

In this framework, coherence describes accessible global correlations, while decoherence characterizes their local dispersion, giving rise to classical structure. Time emerges as the parameterization of the order in which these configurations dynamically reorganize.

5.14 Emergent Quantum Measurement

Decoherence and Measurement: Quantum measurement is the blocking of the flow of information between configurations of Z.

Quantum measurement is interpreted as a process of blocking the flow of information between configurations of the field$Z$, due to the increase in gradients.

$$[|\nabla Z| \uparrow \Rightarrow J^{\mu} \to 0 \Rightarrow \text{se selecciona una configuración efectiva}]$$

- ($|\nabla Z|$): gradient
- (J^{μ}): flow

"Collapse" is a loss of connectivity, not an ontological collapse. This causes the blocking of the flow of information. That is, there is no actual collapse of the wave function.

From the flow:

$$J^{\mu} = \frac{\nabla^{\mu} Z}{1 + \frac{|\nabla Z|^2}{\Lambda^4}}$$

when:

$|\nabla Z|^2 \gg \Lambda^4$

the denominator dominates and we obtain:

$J^{\mu} \to 0$

which implies the suppression of information exchange between configurations.

The measurement does not imply an actual collapse; the collapse corresponds to a loss of connectivity.

In this context:

- multiple configurations cease to communicate
- the system effectively becomes a single one

> Decoherence

- the flow between states is blocked
- interference is lost

> Effective selection

- no elimination of states
- only dynamic disconnection

> Interpretation of collapse

- It is not a fundamental physical process
- it is an emergent phenomenon

> Consistency with flow

- measurement is an extreme case of flow regulation

- it connects directly to the dynamics of the field

Measurement is a disruption of the flow of information; equivalently, there is no collapse, but rather a disconnection between configurations.

The transition from quantum superpositions to definite outcomes does not require a fundamental collapse mechanism, but is interpreted as a process of effective decoherence.

When there are deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) , quantum configurations couple to multiple degrees of freedom, generating entanglement with the effective environment and defining a basis of stable states.

"Collapse" thus corresponds to the effective selection of configurations that remain stable in the face of decoherence, without the need for external imposition or a deterministic process. This process produces an observable loss of coherence in local subsystems, while superposition persists at the global level.

The emergence of definite outcomes reflects the inaccessibility of the interference, rather than its elimination. In this sense, no external observer is required: interaction with the system's dynamic environment is sufficient for the emergence of classical behavior.

Within this framework, situations such as Schrödinger's cat paradox are interpreted as entanglement with the environment, where distinct branches remain globally, yet are inaccessible to one another on a macroscopic scale.

Gravity and geometry emerge from the organization of these correlations: curvature reflects the distribution of energy, while expansion describes the global evolution of spatial relations.

Together, quantum mechanics and geometry integrate consistently: decoherence explains the emergence of classical behavior, while the metric describes the evolution of spatiotemporal relations.

In a cosmological context, physical reality emerges when the metric, time, and decoherence appear together as a result of the evolution from a highly coherent regime toward a structured and stable one.

Rotation curves

- emerging flat behavior

5.15 Effective Dark Matter

Dark Matter as an Effective Component

$$[\rho_{\mathrm{DM}} \sim (\nabla Z)^2]$$

>Galactic rotation curves in the IFMZ model

In the weak-field regime and for approximately spherical configurations, the field (Z) depends solely on the radial coordinate ($Z = Z(r)$). In this case, the effective Poisson equation takes the form:

$$\left[\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d\Phi}{dr}\right) = 4\pi G\left(\frac{dZ}{dr}\right)^2\right]$$

To reproduce flat rotational curves, the tangential velocity must satisfy:

$$\left[v^2(r) = r\frac{d\Phi}{dr} \approx \text{constante}\right]$$

which implies:

$$\left[\frac{d\Phi}{dr} \sim \frac{1}{r}\right]$$

Substituting into Poisson's equation yields the condition:

$$\left[\left(\frac{dZ}{dr}\right)^2 \sim \frac{1}{r^2}\right]$$

whose solution is:

$$[Z(r) \sim \ln r]$$

Consequently, the radial structure of the field generates an effective energy density:

$$\left[\rho_{\text{eff}} \sim \frac{1}{r^2}\right]$$

which produces a logarithmic potential:

$[\Phi(r) \sim \ln r]$

and, therefore, approximately flat rotation curves:

$[v(r) \approx \text{constante}]$

This result shows that the model naturally reproduces the observed galactic dynamics without the need to introduce halos of particulate dark matter.

Gravitational Lensing

- contribution of (ρ_{eff})

Dark matter is interpreted as an effective contribution to the gravitational structure, associated with configurations of the (Z) field that are not observable as baryonic matter but influence the metric.

In this framework, it corresponds to regions where ($\phi = Z - 0.5$) deviations and (∇Z) gradients generate correlations that do not couple to visible channels, but do contribute to the effective energy–momentum tensor.

This can be understood as an effective correction to the curvature of the metric, a non-luminous degree of freedom, or a correlation structure that influences the geometry. This approach does not exclude particle models, but allows their effects to be interpreted as emerging from the organization of the system.

These configurations do not interact significantly with the electromagnetic sector, but generate additional curvature, acting as effective gravitational sources without producing detectable radiation. Configurations with low coupling to decoherence can persist as stable gravitational contributions.

Observational phenomena such as galactic rotation curves and gravitational lensing reflect this additional contribution to geometry, consistent with the presence of non-luminous components in the universe. The dynamical discrepancies observed by Zwicky, traditionally attributed to dark matter (Zwicky, 1933), can be reinterpreted as manifestations of gradients in the field Z , without the need to introduce additional particulate components

Thus, dark matter is described as an emergent effect that modifies large-scale gravitational dynamics, rather than as an independent fundamental entity.

The model naturally reproduces the main characteristics of the observed galactic rotation curves:

- **Inner region:** Newtonian growth
  $$\left[v(r) \sim \sqrt{\frac{GM}{r}} \quad \text{o equivalentemente} \quad v \sim \sqrt{r}\right]$$
- **Intermediate region:** smooth transition between regimes
- **Outer region:** asymptotically constant behavior
  $[v(r) \approx \text{constante}]$

5.16 Emergent effective density

Effective Density $\boldsymbol{\rho_Z}$ with Dual Regime: ($\boldsymbol{\rho_Z}$) varies depending on the dynamic regime; it is neither constant nor universal.

An effective density ρ_0 associated with the field Z is defined, whose magnitude depends on the system's dynamic regime, and is therefore neither constant nor universal:

$$\left[\rho_Z = \rho_0 \left(\frac{|\nabla Z|^2}{\Lambda^4}\right)^{\alpha} \left(1 + \eta \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

- (ρ_Z): emergent effective density
- (ρ_0): density scale
- ($|\nabla Z|^2$): gradient intensity

- (Λ): fundamental scale
- (α): power index
- (η): correction parameter

The base term reproduces MOND in galaxies; the new term generates additional effective mass in clusters, generates effective mass, scale-dependent emergent mass

The functional form is constructed by imposing:

1. **Dynamic regime dependence**

$\rho_Z = \rho_Z(|\nabla Z|^2)$

2. **Power-law behavior (galactic regime)**

$\left(\frac{|\nabla Z|^2}{\Lambda^4}\right)^\alpha$

3. **Additional correction (high-intensity regime)**

$\left(1 + \eta \frac{|\nabla Z|^2}{\Lambda^4}\right)$

This allows for a continuous transition between different physical regimes.

The effective density is not a fixed property, but an emergent quantity; the mass depends on the dynamic state of the field.

In this framework:

- there is no fundamental “dark matter”
- the additional mass arises from the behavior of the field

> **Galactic regime**

When:

$\frac{|\nabla Z|^2}{\Lambda^4} \ll 1$

→ the power term dominates

→ reproduces MOND-like behavior

> **Cluster regime**

When:

$\frac{|\nabla Z|^2}{\Lambda^4} \gtrsim 1$

→ the term with η becomes relevant

→ generates additional effective mass

> **Continuous transition**

- there is no abrupt break
- the system evolves smoothly between regimes

> **Unified interpretation**

- galaxies → base regime
- clusters → extended regime

Mass is not fundamental and emerges from the dynamics of the field; equivalently, “dark matter” is a regime effect.

5.17 Emerging MOND Regime

Natural Emergence of MOND: In the regime of strong gradients, the field equation dynamically produces the MOND acceleration relation.

In the regime of strong gradients of the Z field, the equation of motion dynamically produces an effective acceleration relation equivalent to MOND’s law, without the need to impose it externally.

$$\left[a \sim \sqrt{g_b \cdot a_0}\right]\left[a_0 \sim cH_0 \sim \Lambda^2\right]$$

- (a): acceleration

- (g_b): Newtonian acceleration due to baryonic matter
- (a_0): MOND acceleration
- (c): speed of light
- (H_0): Hubble constant
- (Λ): fundamental scale of the model

MOND emerges without being imposed. The field equation dynamically produces the MOND acceleration relation. The parameter (a_0) is not free; it is fixed by cosmological expansion, linking galaxies with cosmology.

In the regime:

$|\nabla Z|^2 \gg \Lambda^4$

the equation of motion:

$\nabla_\mu \left(\frac{\nabla \backslash mu\, Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}} \right) = V'(Z)$

becomes highly nonlinear.

In this limit:

- the effective flux is reduced
- the field response becomes sublinear

This yields an effective relationship between acceleration and source:

$a^2 \sim g_b \Lambda^2$

which implies:

$a \sim \sqrt{g_b \cdot a_0}$

The dynamics of the field automatically generate an acceleration scale; MOND is not postulated, but rather emerges from the nonlinear regime.

Furthermore:

- a_0 it is not arbitrary
- it is fixed by the cosmological scale

a_0↔expansion of the universe

> Galaxy–cosmology connection

- galactic dynamics depend on H_0
- local and cosmological scales are unified

> Elimination of free parameters

- a_0 is not adjustable
- emerges from the model

> Explanation of rotation curves

- reproduces observed behavior in galaxies
- without the need for additional dark matter

> Dual regime

- weak regime → Newton
- strong regime → MOND

Galactic dynamics is a manifestation of the nonlinear regime of the field; equivalently, galaxies reflect the cosmological structure of the universe.

Tully–Fisher relation

From the above relationship, we obtain:

$\left[v^2 \sim \sqrt{GMa_0} \quad \Rightarrow \quad v^4 \sim GMa_0\right]$

naturally recovering the Tully–Fisher relation, without the need for dark matter.

Rotation curves arise from the effective gravitational potential generated not only by baryonic matter, but also by the spatial gradients of the emergent field (Z). These gradients provide an additional, scale-dependent contribution to gravitational acceleration, dominating in the low-acceleration regime**.**

>Tully–Fisher-like relation in the Z model

The model allows us to derive a relationship between the rotation velocity and the baryonic mass of the galaxy without introducing particulate dark matter.

We start from the effective Poisson equation:

$[\nabla^2\Phi = 4\pi G(\rho_b + |\nabla Z|^2)]$

In the outer regime of the galaxy, where the baryonic density is negligible, the contribution of the field (Z) dominates:

$[\nabla^2\Phi \approx 4\pi G|\nabla Z|^2]$

The model introduces a characteristic acceleration scale:

$[a_0 \sim cH_0]$

which defines the transition between the baryonic regime and the field-dominated regime.

At the transition radius, the following holds:

$\left[\frac{GM}{r^2} \sim a_0\right]$

from which:

$\left[r \sim \sqrt{\frac{GM}{a_0}}\right]$

In the asymptotic regime, the acceleration satisfies:

$\left[a \sim \frac{v^2}{r} \sim a_0\right]$

which implies:

$\left[v^2 \sim \sqrt{GMa_0}\right]$

and, therefore:

$[v^4 \sim GMa_0]$

This relation agrees with the observed Tully–Fisher law, showing that the model naturally reproduces the connection between baryonic mass and galactic dynamics without requiring particulate dark matter.

5.18 Structure Formation and Perturbations

Perturbation equation: Structure evolution.

Describes the evolution of structures through δZ field perturbations in an expanding universe; describes the evolution of perturbations in the expanding universe, including scale effects and nonlinear regulation.

$$\left[\ddot{\delta Z} + 3H\dot{\delta Z} + \left(\frac{k^2}{a^2\left(1+\frac{\zeta k^2}{\Lambda^4}\right)} m_Z^2\right)\delta Z = \delta\rho\right]$$

- (δZ): perturbation
- (H): expansion rate
- (k): scale (wavenumber)
- (a): scale factor
- (ζ): regulator parameter
- (Λ): fundamental scale
- (m_Z): effective mass

- ($\delta\rho$): disturbance source

The equation combines:

- **Expansion:** $3H\delta\dot{Z}$ introduces cosmological friction
- **propagation:** k^2/a^2 describes spatial evolution
- **regulation:**

$$\frac{1}{1+\frac{\zeta k^2}{\Lambda^4}}$$

- **mass:** m_Z^2 sets the growth scale

The evolution of structures depends on scale; perturbations evolve under expansion, mass, and regulation, and small scales are damped.

> Structure formation

- describes the growth of galaxies and clusters
- connects to galaxy formation

> Suppression at high frequencies

- modes with large with k's are damped
- natural and dynamic UV cutoff

> Model stability

- avoids divergences
- controls non-physical growth
- stabilizes the spectrum

The structure of the universe is governed by the dynamics of the field Z .

> Scale dependence

- Different behavior on large and small scales
- key to distinguishing the model

The structure of the universe is controlled by a dynamic cutoff. Or equivalently:

Small scales are suppressed by the dynamics of the Z field.

Effective Sound Speed: Propagation speed of perturbations in the Z field.

The effective sound speedc_s^2 describes the propagation of field perturbations and their modification in nonlinear regimes.

$$\left[c_s^2 = \frac{1}{1+\frac{|\nabla Z|^2}{\Lambda^4}}\right]$$

- ($|\nabla Z|^2$) = field intensity

It controls the propagation of disturbances; in strong regimes it is suppressed, generating natural damping.

The logarithmic regulator modifies the effective kinetic term:

- in weak regime → free propagation
- in strong regime → dynamic suppression

Propagation depends on the field regime; high gradients suppress propagation.

> Linear regime

$|\nabla Z|^2 \ll \Lambda^4 \Longrightarrow c_s^2 \approx 1$

→ standard propagation

> Strong regime

$|\nabla Z|^2 \gg \Lambda^4 \Rightarrow c_s^2 \ll 1$

→ natural damping

> Stability

- prevents UV instabilities
- dynamically regulates the system

The field controls its own propagation.

Linear Perturbation Equation: Describes the evolution of fluctuations (δZ) on the cosmological background.

The linear perturbation equation describes the evolution of small fluctuations in the field relative to the cosmological background.

$$\left[\ddot{\delta Z} + 3H\dot{\delta Z} - c_s^2\nabla^2\delta Z + V''(Z_0), \delta Z = 0\right]$$

- (δZ): fluctuations
- (H): expansion
- (c_s^2): effective sound speed
- ($\nabla^2\delta Z$): gradient
- ($V''(Z_0)$): derivative of the potential

Describes the evolution of fluctuations on the cosmological background. The log damping modifies the propagation of perturbations; at high (k) there is natural damping. Natural UV cutoff.

Consider an expansion:

$Z = Z_0 + \delta Z$

and the equation of motion is linearized:

- the term$3H\dot{\delta Z}$ introduces cosmological friction
- the term describes propagation
- the potential generates an effective mass

The logarithmic regulator modifies propagation on small scales.

The equation describes structure formation; fluctuations evolve under expansion, propagation, and the action of the potential.

> Cosmological expansion

- the term $3H, \dot{\delta Z}$ dampens perturbations
- slows down growth

> Propagation

- controlled by c_s^2
- defines transmission speed

> Logarithmic modification

- at large$k$ (small scales):
  → the regulator reduces propagation

> Natural UV cutoff

High-frequency disturbances are damped.

- prevents divergences
- eliminates the need for external smoothing

The model introduces a dynamic ultraviolet cutoff; consequently, small scales are naturally smoothed out.

5.19 Power spectrum

Power spectrum: Power distribution.

The power spectrum $P(k)$ describes the distribution of perturbation power as a function of scale, characterizing how fluctuations are distributed in the system.

$$\left[P(k) \sim \frac{e^{-k^2/k_*^2}}{(k^2 + m_Z^2)^{2-\epsilon}}\right]$$

- ($P(k)$): perturbation power
- (k): wave number (scale)
- (m_Z): effective mass
- (k_*^2): cutoff scale
- (ϵ): spectral correction

In Fourier space:

- each$k$ mode contributes to the total power
- the field dynamics determine its amplitude

The spectrum results from:

- propagation of perturbations
- effective mass
- high-frequency regulation

The power spectrum describes the energy distribution of the disturbances; the power depends on the scale.

In this context:

- large scales → greater contribution
- small scales → suppressed

> **Large scales**

k → 0

→ dominated by

→ coherent structure

> **Intermediate scales**

→ transition controlled by the denominator

→ defines the shape of the spectrum

> **Small scales**

k → ∞

→ exponential suppression

→ elimination of divergences

> **Natural regularization**

- no overfitting in UV
- the model is stable

The power of the perturbations is filtered by the system's scale; equivalently, the structure emerges with a regularized power distribution.

5.20 Gravitational Lenses

>Gravitational lenses in the Z model

The deflection of light in the model is determined by the effective energy distribution generated by the field (Z). In the weak-field regime, Poisson's equation is:

$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}, \qquad \rho_{\text{eff}} \sim |\nabla Z|^2]$

For galactic configurations, where($Z(r) \sim \ln r$) , we obtain:

$$\left[\rho_{\text{eff}} \sim \frac{1}{r^2}\right]$$

The effective mass within a radius (r) is then:

$$\left[M_{\text{eff}}(r) \sim \int_0^r \rho_{\text{eff}}\,, dV \sim r\right]$$

The angle of light deflection for an impact parameter (b) is given by:

$$\left[\alpha \sim \frac{GM_{\text{eff}}(b)}{b}\right]$$

which leads to:

[$\alpha \sim$ constante]

This behavior is consistent with the gravitational lensing profiles observed in galaxies, where the deflection remains approximately constant over wide radial ranges.

Under the assumption of no significant anisotropic stresses, we have ($\Phi \approx \Psi$), so the deflection of light is completely determined by the effective gravitational potential generated by the field (Z).

In this way, the model reproduces gravitational lensing effects without requiring particulate dark matter, interpreting these phenomena as manifestations of the spatial structure of the field.

5.21 Extreme Structures

Following the formation of a black hole, the system enters a regime in which the classical description is no longer sufficient and additional degrees of freedom are required.

Information is not eliminated, but rather redistributed among different levels of the system, becoming partially inaccessible in the macroscopic description. In the field (Z) , this regime corresponds to configurations with high deviations ($\phi = Z - 0.5$) and gradients (∇Z) , where the dynamics are dominated by highly nonlinear correlations.

A distinction can be made between macroscopically accessible information and information encoded in inaccessible microscopic degrees of freedom. The evolution is interpreted as a reorganization of information: local accessibility is lost, but not necessarily the total information.

In regions of extreme curvature, the dynamics of spacetime exceed classical intuitions. Time dilation causes processes near the horizon to appear slowed down to an external observer, while locally the evolution continues normally. In this regime, general relativity reaches its limits and quantum gravity effects are expected.

As a consequence, information becomes inaccessible to external observers, correlations reorganize in a non-classical manner, and the distinction between classical and quantum descriptions blurs.

The final phase can be interpreted as a process of re-emission of energy and information. In the semi-classical description, Hawking radiation implies a gradual loss of mass and a transfer of energy to the environment (Hawking, 1975), understood as a redistribution of degrees of freedom.

In the field(Z) , this evolution corresponds to a transition from high gradients to smoother regimes, where energy and correlations are redistributed. This process does not reduce global entropy: even as organized structures emerge, total entropy continues to increase.

Thus, the evolution in these extreme regimes is described as a continuous transformation of the system, in which energy and information change form and accessibility without violating fundamental laws.

5.22 Extreme Structures (Black Holes)

Nodes of coherence: Black holes

Black holes can be interpreted as the limiting regime of correlation concentration in the field (Z) , where the deviations ($\phi = Z - 0.5$) and the gradients (∇Z) reach extreme values.

In these regions, the emergent metric exhibits intense curvature, manifesting as time dilation and information confinement, in accordance with general relativity (Einstein, 1915). They do not represent a breakdown of the theory, but rather highly stable configurations under extreme conditions, where the system's dynamics reach their limits.

From this perspective, black holes are not boundaries of annihilation, but rather local high-density domains in which the geometric structure and correlations are maximally concentrated. Their existence reflects the system's capacity to simultaneously sustain distinct dynamic regimes: global expansion and intense gravitational structures.

The formation of a black hole can be understood as the result of a gravitational collapse that concentrates energy and degrees of freedom in a highly compact region. During this process, an event horizon emerges that delimits a region inaccessible to external observers, while the system's entropy increases and is associated with the area of the horizon. The results of Bekenstein and Hawking suggest that gravitational geometry possesses thermodynamic and informational content. Within this framework, this relationship emerges naturally, since the$Z$ field directly encodes the organization of the system's information. (Bekenstein, 1973; Hawking, 1975).

Information is not destroyed, but rather ceases to be externally accessible, remaining encoded in the system's degrees of freedom. In the (Z) field, this regime corresponds to configurations with high deviations and gradients, indicating a high-curvature domain. Time dilation does not imply the stopping of time, but rather a difference between the external description and the internal evolution of the system.

In this framework, the classical singularity is replaced by a regime of correlation saturation in which the $((\nabla Z)^2)$ invariant approaches a finite upper limit. Logarithmic corrections regulate the growth of curvature, preventing divergences and giving rise to a state of maximum correlation density rather than a divergent geometry.

In regions of extreme curvature, the classical description based on trajectories and smooth geometry ceases to be valid, giving way to quantum gravity effects. This change does not imply a reversal of the dynamics, but rather a regime transition in which classical variables are replaced by quantum states and correlations.

In this regime, well-defined classical states lose their operational validity; the description requires quantum superposition and correlations, and the evolution continues without being representable by classical intuitions.

Thus, black holes constitute transition domains between classical and quantum physics, where the apparent indeterminacy reflects the limits of the classical description and not a reversal of the physical process.

5.23 Extreme Structures (Information)

Page curve: A model of the entanglement entropy of radiation that demonstrates the preservation of information.

The Page curve describes the temporal evolution of the entanglement entropy of emitted radiation, showing that information is not lost but is gradually recovered.

$$\left[S_{\text{ent}}(t) = \left[(M_0^3 - t)^{2/3} A \cdot t^{\alpha\backslash}\right]\right] [\alpha < 1]$$

- ($S_{\text{ent}}(t)$): entanglement entropy
- (t): time
- (M_0): initial mass of the system
- (A): scale parameter
- (α): growth rate

Demonstrates information preservation. Describes the evolution of entropy. Information is gradually recovered

The behavior is divided into two regimes:

- **Early stage:**

$S_{\text{ent}}(t) \sim A \cdot t^{\alpha}$

- **Late stage:**

$S_{\text{ent}}(t) \sim (M_0^3 - t)^{2/3}$

The minimum function determines the physical behavior in each regime.

Entropy does not grow indefinitely; information is recovered in the final phase.
In this framework:

- the radiation initially appears thermal
- later reveals correlations

> Initial phase

- increase in entropy
- apparent loss of information

> Page point

- maximum entropy
- Behavioral transition

> Final phase

- decrease in entropy
- information recovery

> Consistency with the model

- logarithmic corrections introduce correlations
- ensure unitarity

Information is not lost, but is progressively released; equivalently, Hawking radiation is informationally complete. The horizon corresponds to a region where the flow of information is nullified.

> Dynamic isolation

- regions remain disconnected
- there is no transfer of information

> Definition of the event horizon

- it is not a singularity
- it is a dynamic condition of the flow

> Consistency with saturation

- Blockage arises from the strong regime
- it does not require external conditions

A horizon is not a geometric barrier, but an informational one; equivalently, where the flow ceases, a horizon emerges.

5.24 Extreme Structures (Radiation and Information)

Modified Hawking Radiation: The Hawking spectrum receives logarithmic corrections that preserve unitarity.

Hawking radiation receives logarithmic corrections derived from the Z field, which introduces deviations from the perfect thermal spectrum and allows for the preservation of unitarity.

$$\left[n(\omega) = \frac{1}{e^{\omega/T_H} - 1} \cdot \left[1 + \epsilon \mathrm{In}\left(1 + \frac{\omega^2}{\Lambda^2}\right)\right]\right]$$

- ($n(\omega)$): occupation distribution
- (ω): frequency
- (T_H): Hawking temperature
- (ϵ): correction parameter
- (Λ): fundamental scale

The emission is not perfectly thermal; it contains correlations. It introduces logarithmic corrections. The information is encoded in the correlation pattern.

In the model:

- the logarithmic term modifies the dynamics of the field
- it introduces correlations between modes

This alters the standard spectrum:

$\frac{1}{e^{\omega/T_{H-1}}}$
adding a frequency-dependent correction.

The radiation is not perfectly thermal; the emission contains correlations.

In this framework:

- the spectrum is slightly distorted
- information is not lost

> Non-thermality

- deviation from the blackbody spectrum
- small corrections dependent on ω

> Information preservation

- correlations encode information
- avoids the information loss paradox

> Unitarity

- Evolution is reversible in principle
- information is released gradually

> Observable signature

- possible measurable deviation from the spectrum
- Λ scale dependence

Hawking radiation carries information rather than destroying it; equivalently, non-thermality constitutes the signature of unitarity.

5.25 Dark Energy

Dark energy is interpreted as an effective contribution to the large-scale dynamics of the metric, responsible for the acceleration of expansion.

Phenomenologically, it can be described by an additional term in the cosmological equations, equivalent to a cosmological constant or a dynamic contribution not associated with conventional matter or radiation (Planck Collaboration, 2018). Cosmological observations indicate an effective behavior close to$w \approx -1$. In this framework, this regime naturally emerges as a property of the effective potential of the$Z$ field around equilibrium.

In the field (Z) , it corresponds to regimes where the deviations ($\phi = Z - 0.5$) and the gradients (∇Z) are small and homogeneous, generating a nearly uniform contribution to the energy–momentum tensor.

This term does not act as an external force, but rather as a property of the system's global structure that modifies the evolution of the scale factor. It should not be interpreted as an independent substance, but rather as the collective behavior of the system in the large-scale limit.

In this framework, dark energy represents the most homogeneous component of the contribution from the field (Z), associated with a regime in which the local structure is weak and the cosmological evolution dominates.

Gravity and dark energy coexist as complementary regimes: the former dominates locally through curvature, while the latter governs the global dynamics of expansion.

Thus, dark energy emerges as an effective description of the global evolution of the metric, associated with the dynamics of the (Z) field, without requiring a specific fundamental entity.

Emergent Dark Energy: Dark energy is not an entity; it is the ground state of the Z field.

$$[\rho_Z \sim \Lambda^4][p_Z \approx -V(Z)][\rho_Z + 3p_Z \approx -2V(Z) < 0]$$

- (ρ_Z): energy density of the field
- (p_Z): effective pressure
- ($V(Z)$): field potential
- (Λ): fundamental scale

Cosmic acceleration emerges from the potential at ($Z = 0.5$). It produces cosmic acceleration.Λ is not a free parameter but a property of equilibrium.

Dark energy is not introduced as an independent entity, but rather emerges as the ground state of the field in equilibrium:

$$Z = 0.5$$

Cosmic acceleration arises directly from the field's equilibrium state:

In the cosmological background regime:

$\dot{Z} \approx 0, \quad \nabla Z = 0$

the field energy reduces to:

$\rho_Z \approx V(Z)$

and its associated pressure is negative:

$p_Z \approx -V(Z)$

This implies:

$\rho_Z + 3p_Z < 0$

a necessary condition for accelerated expansion.

Dark energy corresponds to the value of the potential at the system's minimum.

In this framework:

- no ad hoc cosmological constant is introduced
- acceleration is a natural consequence of equilibrium

> **Cosmic acceleration**

- the potential generates negative pressure
- drives accelerated expansion

> **Non-arbitrary origin**

- Λ It is not a free parameter
- it is determined by the structure of the field

> **Interpretation of the vacuum**

- The vacuum has energy
- It corresponds to the ground state of the system

> **Conceptual unification**

- dark energy → ground state
- gravity → deviations
- matter → perturbations

Dark energy constitutes the natural state of the universe; equivalently, cosmic acceleration is a property of equilibrium.

Dark Energy as a Homogeneous Component of the Z Field

Dark energy is interpreted as an effective and homogeneous contribution to the dynamics of the metric, responsible for cosmological acceleration.

In the *Z-field*, it arises in regimes where the deviations $\phi = Z - 0.5$ and the gradients ∇Z are small on a large scale, producing a nearly uniform contribution to the energy–momentum tensor.

It does not need to be identified as an independent substance, but rather represents the global behavior of the system in the large-scale limit.

In this framework:

1. It is the most homogeneous component of the *Z-field's* contribution.
2. It reflects the regime where the local structure is weak.
3. It dominates the evolution of the scale factor on cosmological scales.

The acceleration of expansion is interpreted as a property of the metric's evolution under this homogeneous contribution, consistent with cosmological constant-type descriptions.

In summary, dark energy corresponds to the global contribution of the Z field that governs the dynamics of accelerated expansion.

Equation of state: Describes the behavior of dark energy.

The equation of state$w$ describes the macroscopic behavior of the effective dark energy associated with the field (Z), relating its pressure (p) to its energy density (ρ).

$$\left[w = \frac{p}{\rho}\right]\left[w \approx -1 + \frac{V'(Z)^2}{H^2 V(Z)}\right]$$

- (w): equation of state parameter
- (p): effective pressure
- (ρ): energy density
- ($V'(Z)$): potential derivative
- (H): expansion rate (Hubble)

Describes the behavior of dark energy. Describes dynamic behavior.

In the cosmological regime:

- The potential dominates over the kinetic term
- The field evolves slowly (effective slow-roll)

Therefore:

- ($w \approx -1$) corresponds to dynamic equilibrium
- Deviations are controlled by:

$$\left[\frac{V'(Z)^2}{H^2 V(Z)}\right]$$

which measures the distance of the system from equilibrium.

$w \approx -1$ but with dynamic corrections

This implies that dark energy is not strictly constant, but emergent and evolving.

> **Dynamic dark energy**

- It evolves with (Z)
- It is not a fundamental constant

> **Cosmological constant limit**

- If ($V'(Z) \to 0$) $\Rightarrow$ ($w \to -1$)

> **Observable cosmological evolution**

- Deviations from (w) encode the dynamics of the universe
- They allow us to distinguish between theoretical models

> **Connection to observations**

- Type Ia supernovae
- BAO
- CMB

The $w = -1$ deviation measures the dynamics of the Z field

$\boldsymbol{w(z)}$ **equation of state:** A dynamic equation of state parameter, key to distinguishing the model from ΛCDM.

The equation of state parameter $w(z)$ describes the dynamics of the effective dark energy of the field Z , constituting a key prediction that allows the model to be distinguished from ΛCDM.

$$\left[w(z) = -1 + \frac{2(\kappa + \zeta/\Lambda^4)}{9H^2} \cdot \frac{V'(Z)^2}{V(Z)}\right]\left[w(z) \approx -1 + A \cdot \frac{(1+z)^{2\beta}}{H(z)^2}\right]$$

- ($w(z)$): equation of state parameter
- (κ): kinetic parameter
- (ζ): regulator parameter
- (Λ): fundamental scale
- ($H(z)$): expansion rate
- ($V'(Z)$): potential derivative
- ($V(Z)$): potential
- (A): effective amplitude
- (β): evolution index

Falsifiable prediction: $\left(w(z)\right)$ evolves smoothly with redshift. ($w(z) \neq -1$) in the past.

- From the density and pressure of the Z field:
  the kinetic term and the potential determine w
- the regulator introduces regime-dependent corrections

This results in a dynamic deviation from:

$$w = -1$$

Dark energy is not constant:

$w(z) \neq -1$ in the past

In this framework:

- the field evolves over time
- the expansion is not purely exponential

> **Falsifiable prediction**

- $w(z)$ it varies with redshift
- key difference from ΛCDM

> **Smooth evolution**

- the deviation increases toward the past
- controlled by β

> **Observational signature**

- measurable with supernovae, BAO, CMB
- allows the model to be validated or ruled out

> **Connection to field dynamics**

- the deviation depends on $V'(Z)$
- connects cosmology with microstructure

Dark energy is dynamic and not constant; equivalently, the expansion of the universe evolves with the history of the field Z .

5.26 Dark Energy and Cosmology

>Cosmology of the Z model

On cosmological scales, the field (Z) can be considered approximately homogeneous ($Z = Z(t)$), in accordance with FLRW-type spacetime symmetry. In this regime, spatial gradients are negligible and the dynamics are dominated by the effective potential.

The kinetic invariant takes the form:

$[X = -\dot{Z}^2]$

and the energy and pressure densities associated with the field are:

$[\rho_Z = 2XF'(X) - F(X) + V(Z), \qquad p_Z = F(X) - V(Z)]$

In the slow evolution regime, ($\dot{Z} \approx 0$), we obtain:

$[\rho_Z \approx V(Z), \qquad p_Z \approx -V(Z)]$

which corresponds to a state parameter:

$[w \approx -1]$

This behavior is equivalent to that of an effective cosmological constant, indicating that the field (Z) can explain the acceleration of the universe without introducing an additional independent component.

On the other hand, perturbations of the field,

$[Z = Z(t) + \delta Z(x, t),]$

generate spatial contributions of the form:

$[\rho_{\text{eff}} \sim |\nabla Z|^2,]$

which can act as a source of structure formation, effectively playing the role of dark matter.

In this way, the model unifies within a single framework:

- cosmological acceleration (via$\left(V(Z)\right)$),
- galactic dynamics (via($|\nabla Z|^2$)) ,
- and structure formation (through field perturbations).

This unification offers a coherent alternative to the standard ΛCDM model, with possible observational deviations in the growth of perturbations and in the large-scale power spectrum.

5.27 Early Universe and Radiation

The Origin of Radiation in the Early Regime

The Big Bang is not interpreted as an explosion in a pre-existing space, but as the beginning of a dynamic regime in which the metric and time acquire physical meaning.

In this early state, the universe was dense and hot, with matter and radiation forming a coupled plasma in equilibrium, lacking distinct structures and preventing the free propagation of light.

In the field (Z) , this regime corresponds to the emergence of deviations ($\phi = Z - 0.5$) and gradients (∇Z) , which allow for distinguishable configurations and the onset of decoherence processes.

Decoherence does not occur as a single event, but as a continuous process accompanying expansion, allowing for the progressive decoupling of degrees of freedom and the formation of stable structures.

As the system expands and cools, the decoupling between matter and radiation allows for the free propagation of light, giving rise to cosmic background radiation.

Thus, the radiation does not arise from a singular event, but rather as an excitation of the system that evolves from a coupled regime toward a free one.

Taken together, the Big Bang marks the beginning of a dynamic in which geometry, matter, radiation, and time emerge jointly from the evolution of the system's correlations.

5.28 Early Universe and Initial Regime

Pre-Geometric Regime and Origin of the Universe

The origin of the universe can be interpreted as an extreme regime where current theories cease to be fully applicable.

This initial state is characterized by:

- Absence of defined classical geometry.
- Lack of an operational notion of time.
- The dominance of global quantum correlations.

Within the framework of the Z field, it corresponds to a pre-geometric phase in which spacetime has not yet emerged.

From this perspective:

- The Big Bang is not an explosion in a pre-existing space, but rather the beginning of dynamic geometry.
- Expansion describes the evolution of the system's own structure.

The transition to a physical regime occurs when:

- Spatial relationships (metrics) emerge.
- A dynamic order is established (time).

The Z field acts as a conceptual tool to describe this transition from a system without geometry to one with an observable physical structure.

Thus, the origin of the universe is understood as a regime shift from pre-geometric to geometric rather than as a fully described point event.

6. Emergence of Time

Time equals order of configurations

6.1 Emergence of the Physical Description

Time is not postulated as a fundamental variable, but rather emerges as an effective parameter associated with the evolution of the macroscopic state of the field (Z) .

The problem of time in fundamental physics arises from the incompatibility between its dynamic role in general relativity and its external nature in quantum mechanics.

The emergent time described here is equivalent to the cycle proposed in previous works (Pérez Cortes, 2026b). It was proposed that time can be interpreted as an emergent variable associated with the evolution of the system's state. Now derived directly from the dynamics of the Z field.

In the present framework, this idea is formalized through the dynamics of the Z field: time emerges as an effective parameter that orders the evolution of correlations, in line with the relational interpretation of dynamics and consistent with the decoherence processes described by Zurek.

6.2 Properties of Emergent Time

Fundamental Laws of Emergent Time

In this framework, time is not a fundamental variable, but an emergent property associated with the evolution of the Z field.

It is characterized by the following properties:

1. Absence of prior time: Without gradients or differentiable correlations, a notion of time cannot be defined, since there is no structure that orders changes.
2. Dynamic Dependence: Time does not elapse independently, but is linked to the evolution of the system's configurations; in the absence of change, it loses physical meaning.
3. Order of evolution: Time corresponds to an effective parameterization of the order in which configurations reorganize, and not to an external entity.
4. Quantum compatibility: Quantum evolution can be described without a fundamental time, interpreting the time parameter as a variable emerging from the internal dynamics.

Taken together, time emerges only when the system admits distinguishable configurations and coherent evolution.

Homogeneous Expansion as the Ground State: Cosmological expansion has no external cause; it is the only dynamics compatible with ($Z = 0.5$)**.**

Cosmological expansion does not require an external cause, but rather emerges as the only dynamics compatible with the equilibrium state of the Z field.

$$Z=0.5 \Rightarrow \nabla Z=0 \Rightarrow \text{no forces} \Rightarrow \text{homogeneous expansion}$$

- (Z): field
- (∇Z): field gradient

Matter modulates the expansion $((\delta Z))$; it does not cause it. The only possible evolution is isotropic expansion. Maximum symmetry does not allow for collapse or a preferred direction.

In the state:

$Z = 0.5$

the following holds:

- maximum coherence
- absence of gradients

$\nabla Z = 0$

which implies:

- no internal forces
- no preferred direction

Therefore, the only compatible evolution is uniform expansion.

Expansion is the natural state of the system; it is not caused, but rather constitutes the ground state.

> It requires no external mechanism

- It does not require fundamental dark energy
- It emerges from equilibrium

> Maximum symmetry

- there are no preferred directions
- the universe is isotropic

> Role of matter

- matter introduces deviations δZ
- it modulates expansion, but does not generate it

> Impossibility of global collapse

- Equilibrium does not allow for total contraction
- only local structures

The expansion of the universe is a manifestation of field equilibrium; equivalently, maximum symmetry leads to expansion rather than rest.

6.3 Nature of emergent time

Expansion is not an initial event, but the dynamic manifestation of this structure: it describes the reorganization of field correlations while maintaining stability around equilibrium.

Thus, the observable universe does not correspond to a random selection, but to the realization of dynamically stable configurations determined by the structure of the Z field.

- (Z) = effective field
- (0.5) = equilibrium point

Information is dynamically conserved; it connects with entropy, causality, and temporal evolution.

Consequently, time emerges alongside the system’s dynamics and reflects the order in which its configurations reorganize in a stable manner.

Continuous Nature of Time

Time is an emergent property associated with the continuous evolution of the configurations of the field (Z) , determined by the reorganization of the deviations ($\phi = Z - 0.5$) and their gradients (∇Z) .

In certain regimes, this evolution can be represented by discretized descriptions, but these "steps" do not correspond to a fundamental structure, but rather to an effective approximation of the dynamics.

Matter and energy arise from the stabilization of correlations within the field, rather than from discrete events, giving rise to persistent configurations.

Although this approach bears analogies to proposals for quantum gravity, in this model time is not discrete in its origin but continuous, admitting discrete representations only as approximate descriptions in specific domains.

Thus, time is interpreted as the continuous order of the system's evolution, whose discretization constitutes an effective representation and not a fundamental property.

6.4 Temporal Dynamics

$$\left[\frac{\partial Z}{\partial t} \sim -\frac{\delta S}{\delta Z}\right]$$

In quantum mechanics, evolution is described by an external time parameter. In this framework, this parameter is interpreted as an effective variable that orders the evolution of the system.

Time is not an independent entity, but rather emerges from the dynamics of the field (Z) , through the reorganization of the correlations associated with the deviations ($\phi = Z - 0.5$) and their gradients (∇Z) .

Thus, time does not flow externally, but rather corresponds to the internal order in which the system's configurations evolve consistently. This allows for a reinterpretation of quantum dynamics without requiring absolute time: the time parameter in equations such as Schrödinger's describes the internal evolution of the system and not a fundamental variable.

Time does not precede physical manifestation, but rather emerges from the dynamic organization of the field(Z) . It arises when there are deviations and finite gradients that allow us to distinguish configurations and establish relationships between them.

In this context, time corresponds to the order in the evolution of states, giving rise to distinctions between configurations, consistent causal relationships, and an effective flow of change.

Causality is not imposed externally, but rather results from the coherent organization of these variations. Thus, time is interpreted as the manifestation of the internal order in which the system's configurations reorganize themselves in a stable manner.

6.5 Time-Geometry Relationship

Joint Emergence of Metric and Time

The metric structure emerges when the system can distinguish configurations, which requires deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) that allow for the definition of relations, distances, and scales.

From this relational structure, an order is established in the evolution of configurations. This order is not imposed externally, but rather arises from the dynamics of the system and constitutes what is interpreted as time.

In the absence of gradients and correlations, there are no distinguishable configurations or an order of change, so time lacks physical meaning.

Thus, metric and time are not independent entities, but rather emergent properties that appear together when the system admits a consistent relational structure.

6.6 Entropy and the Arrow of Time

Emergent Time as an Information Cycle: Time is the cyclical process of accumulation and release of information in Z.

Time is not a fundamental variable, but an emergent process associated with the cycle of accumulation and release of information in the Z field.

$$\left[\frac{\partial Z}{\partial t} \sim -\frac{\delta \mathcal{S}}{\delta Z}\right]\left[\frac{dS_Z}{dt} \geq 0\right]$$

- ($\frac{\partial Z}{\partial t}$): temporal evolution of the field
- ($\mathcal{S}$): functional of the system
- (S_Z): field entropy

defines the arrow of time through the process of accumulation and release. The arrow of time emerges from the monotonic increase in entropy.

The evolution of the field is governed by an effective variational principle:

- the system evolves toward more stable configurations
- this evolution corresponds to changes in entropy

This induces gradient-like dynamics:

$\frac{\partial Z}{\partial t} \sim -\frac{\delta \mathcal{S}}{\delta Z}$

and an irreversibility condition:

$\frac{dS_Z}{dt} \geq 0$

Time does not flow, but rather emerges from informational change; equivalently, the arrow of time corresponds to the direction of increasing entropy.

Within this framework:

- there is no external time
- time is a property of change

> Arrow of time

- defined by the increase in entropy
- intrinsic to the system

> Cyclical dynamics

- accumulation → storage of information
- release → redistribution

> Irreversibility

- evolution is not symmetric over time
- emerges from the dynamics of the field

> Relationship with measurement

- decoherence increases entropy
- It fixes a temporal direction

Entropy, expansion, and the emergence of structure

7.6 Entropy, expansion, and the emergence of structure

Entropy remains the measure of the number of microscopic configurations compatible with a macroscopic state, but its evolution is understood within an expanding system.

In the field (Z) , the appearance of deviations ($\phi = Z - 0.5$) and gradients (∇Z) is associated with decoherence processes that redistribute correlations, increasing entropy by making certain degrees of freedom inaccessible at the local level.

The entropic increase does not imply the generation of absolute disorder, but rather an increase in the number of accessible configurations of the system. In this context, the formation of macroscopic structures can coexist with a global increase in entropy.

In regimes without a metric structure, it is not possible to distinguish physical states. The emergence of deviations and gradients allows for the formation of structures and the definition of states through decoherence processes.

Cosmological expansion broadens the space of accessible states, facilitating the formation of new configurations and contributing to entropic growth.

Irreversibility does not require an additional fundamental mechanism but emerges from the loss of access to microscopic information. As configurations interact, energy and information are redistributed among degrees of freedom, generating dissipation and effective irreversibility.

Global dynamics thus describe an evolution in which large-scale homogenization and the formation of local structures coexist, reflecting the continuous reorganization of the system's correlations.

Together, entropy, decoherence, and expansion form a unified process: the system's dynamics reorganize correlations, define the accessibility of information, and govern the statistical evolution of the universe.

6.7 Holographic Limit and Degrees of Freedom

Total Entropy and Number of Degrees of Freedom: Holographic Limit of the System.

The total entropy of the system is limited by a holographic principle, according to which the maximum information in the universe scales with area and not with volume.

$$\left[S_Z^{\text{total}} \sim \frac{A}{l_P^2}\right]\left[S_Z^{\text{total}} \sim 10^{122}\right]\left[N_{\text{total}} \sim S_Z\right]$$

- (S_Z^{total}): total entropy of the system
- (A): characteristic area (horizon)
- (l_P): Planck length
- (N_{total}): total number of degrees of freedom

The total amount of information in the universe is holographically limited. Define the number of degrees of freedom. Each unit of entropy corresponds to one degree of freedom.

The entropy defined by the field:

$$S_Z = \int dA \ \text{In}\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)$$

reaches a maximum when:

- the gradients saturate
- information is distributed at the boundary

This leads to:

$S_Z^{\text{total}} \propto A$

and, in fundamental units:

$S_Z^{\text{total}} \sim \frac{A}{l_P^2}$

The total amount of information in the universe is bounded; the maximum amount of information is proportional to the area.

In this framework:

- the universe has a finite number of degrees of freedom
- information does not grow indefinitely with volume

> **Holographic principle**

- information resides on surfaces
- volume is emergent

> **Counting degrees of freedom**

$N_{\text{total}} \sim S_Z$

→ each unit of entropy represents a degree of freedom

> Cosmological scale
$S \sim 10^{122}$
→ Consistent with the observable universe

> Fundamental interpretation

- the universe is a finite system in terms of information
- physics is constrained by that limit

The universe possesses a finite number of bits; equivalently, reality is limited by the available information.

6.8 Holographic Limit and Entropy.

Entanglement Entropy: The informational content of the system, encoded in Z gradients.

Entanglement entropy S_Z is defined as a measure of the system's informational content, encoded in the gradients of the field Z over a surface.

$$\left[S_Z = \int_\Sigma dA \, In\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

- (S_Z): entanglement entropy
- (Σ): surface of integration
- (dA): area element
- ($|\nabla Z|^2$): gradient intensity
- (Λ): fundamental scale

Information does not reside in the volume but at the boundaries where Z changes. It measures information. Entropy scales with area because the maximum gradients occur at the horizon.

Entropy is constructed under the principle:

information~field variation

Given that:

- gradients encode correlations
- maximum variations occur at boundaries

the dominant contribution is concentrated on surfaces.

The logarithmic term:

- regularizes the contribution
- saturates in extreme regimes

The system's information is not distributed throughout the volume; it is localized at the boundaries.
In this framework:

- gradients represent correlations
- surfaces concentrate information

> Area law

- entropy scales with area
- not with volume

$$\boxed{S \propto A}$$

> High-information regions

- Maximum gradients dominate entropy
- typically at boundaries

> Natural regulation

- the log function prevents divergences
- introduces informational saturation

> Holographic interpretation

- the system's information is encoded in surfaces
- Volume emerges from correlations

The information of the universe is stored at its boundaries; equivalently, gradients of$Z$ constitute the measure of information.

6.9 Area Entropy in Black Holes: The entropy of a black hole scales with its area because the information is in the gradients of the event horizon.

The entropy of a black hole measures the system's information content and is encoded in its surface, specifically in the gradients of the$Z$ field at the horizon.

$$\left[S_Z = \int_\Sigma dA \,\mathrm{In}\left(\frac{|\nabla Z|^2}{\Lambda^4}\right)\right]\left[S_Z \sim \frac{A}{l_P^2}\right]$$

- (S_Z): entropy
- (Σ): surface area of the horizon
- (dA): area element
- ($|\nabla Z|^2$): gradient intensity
- (Λ): fundamental scale
- (A): horizon area
- (l_P): Planck length

Information does not reside in the interior volume but at the transition boundary. It scales with the area. The horizon is the region where the geometry reconfigures.

At the horizon:

- field gradients are maximal
- the flow of information is blocked

$J^\mu \to 0$

This concentrates the information on the surfaceΣ , where:

- the logarithmic term dominates
- entropy becomes a surface quantity

Integrating over the area:

$S_Z \propto A$

At the horizon:

- the field gradients are maximal
- the information flow is blocked

$J^\mu \to 0$

This concentrates the information on the surfaceΣ , where:

- the logarithmic term dominates
- entropy becomes a surface quantity

Integrating over the area:

$S_Z \propto A$

Information does not reside in the interior volume; it is localized at the boundary.

In this framework:

- the boundary contains all relevant information
- the interior is emergent

> **Area scaling**

- entropy depends on the area
- reproduces expected behavior

> Horizon as an interface

- field transition region
- where the geometry reorganizes

> Holographic nature

- the system is described by its surface
- the volume does not provide independent degrees of freedom

> Consistency of the model

- derives directly from the gradients of Z
- It requires no external postulates

Black holes store information on their surface; equivalently, the event horizon acts as an informational layer rather than a singularity.

6.10 Solution to the cosmological constant problem

The cosmological constant problem consists of the discrepancy between the vacuum energy density predicted by quantum theories and the cosmologically observed value. In natural units:

$$\rho_{\text{vac}}^{\text{QFT}} \sim M_P^4 \quad \text{vs} \quad \rho_{\Lambda}^{\text{obs}} \sim 10^{-122} M_P^4$$

This discrepancy suggests the need for a mechanism that dynamically suppresses vacuum energy.

Model framework

In this work, dark energy emerges from the effective field$Z$, whose dynamics simultaneously define:

- cosmological expansion
- the entropy of the universe
- the total number of degrees of freedom

The total entropy is given by:

$$S_Z = \frac{A}{4l_P^2}$$

where the area corresponds to the apparent horizon:

$$A = \frac{4\pi}{H^2}$$

Therefore:

$$S_Z = \pi \frac{M_P^2}{H^2}$$

Fundamental relation

Using the Friedmann equation:

$$H^2 = \frac{8\pi}{3M_P^2} \rho_Z$$

we obtain:

$$S_Z = \frac{3}{8} \frac{M_P^4}{\rho_Z}$$

Key result

Identifying:

$$N \equiv S_Z$$

we obtain:

$$\boxed{\rho_\Lambda \propto \frac{1}{N}}$$

This implies that the vacuum energy is not a fundamental constant, but rather an emergent quantity inversely proportional to the number of degrees of freedom of the universe.

In this framework:

- vacuum energy is distributed over the accessible degrees of freedom
- it is not necessary to cancel quantum contributions
- 10^{-122} suppression emerges naturally from the size of the system

>Observed value

Using:

$N \sim 10^{122}$

we directly obtain:

$\rho_\Lambda \sim 10^{-122} M_P^4$

in agreement with cosmological observations.

> Cosmic coincidence

Problem

Why does the following hold true in the present era:

$\rho_m \sim \rho_\Lambda$

despite its different time dependencies?

Solution in the model

Given that:

$$\rho_\Lambda = \frac{3}{8}\frac{M_P^4}{S_Z}$$

and:

$$S_Z \propto \frac{1}{H^2}$$

we obtain:

$\rho_\Lambda \propto H^2$

Result

$$\boxed{\rho_\Lambda(t) \sim H(t)^2}$$

Dark energy follows the evolution of the universe:

- in the past:H large $\rightarrow \rho_\Lambda$ greater
- in the present:H small $\rightarrow \rho_\Lambda$ comparable to ρ_m

The cosmic coincidence is a dynamic consequence, not a fine-tuning.

> Observational prediction

The model predicts that:

$w(z) \neq -1$

and evolves smoothly with redshift:

$w(z) = -1 + \mathcal{O}\left((1+z)^{2\beta}\right)$

This approach implies that:

- the cosmological constant is not constant

- vacuum energy is a thermodynamic variable
- expansion and information are deeply connected

Dark energy is determined by the entropy of the universe, which in turn means that the cosmological constant emerges from the informational capacity of spacetime.

6.11 Derivation of the number of cosmological degrees of freedom

The total number of degrees of freedom of the observable universe is derived from the entropy of the field `$Z$ `, identified with the holographic entropy associated with the cosmological horizon.

It is assumed that the entropy of the system is given by:

$$S_Z = \frac{A}{4\, l_P^2}$$

where:

A: area of the causal surface

l_P^2: Planck length ($c = h = 1$ al natural units)

>Cosmological horizon

The relevant surface is identified with the apparent horizon of an FRW universe:

$$R_H = \frac{1}{H}$$

therefore:

$$A = 4\pi R_H^2 = \frac{4\pi}{H^2}$$

Substituting:

$$S_Z = \frac{1}{4 l_P^2} \cdot \frac{4\pi}{H^2} = \frac{\pi}{l_P^2 H^2}$$

Using:

$$l_P^2 = \frac{1}{M_P^2}$$

we obtain:

$$S_Z = \pi \frac{M_P^2}{H^2}$$

In the model, the expansion is governed by:

$$H^2 = \frac{8\pi G}{3} \rho_Z$$

and in steady state:

$$\rho_Z = \Lambda^4$$

Furthermore:

$$G = \frac{1}{M_P^2}$$

therefore:

$$H^2 = \frac{8\pi}{3 M_P^2} \Lambda^4$$

Substituting intoS_Z :

$$S_Z = \pi \frac{M_P^2}{H^2} = \pi \frac{M_P^2}{\frac{8\pi}{3 M_P^2} \Lambda^4}$$

$S_Z = \frac{3}{8}\frac{M_P^4}{\Lambda^4}$

> Exact result

$$\boxed{S_Z = \frac{3}{8}\frac{M_P^4}{\Lambda^4}}$$

> Numerical value

Using:

$\frac{\Lambda^4}{M_P^4} \approx 10^{-122}$

we obtain:

$$\boxed{S_Z \approx 10^{122}}$$

> Identification with degrees of freedom

$$\boxed{N_{\text{total}} = S_Z}$$

Physical interpretation

The number of degrees of freedom in the observable universe is determined by:

the Planck scale

the cosmological scale

and fixed by the expansion via the horizon.

$$\boxed{N_{\text{total}} \propto \frac{1}{H^2}}$$

the informational content of the universe is fixed by its horizon

or equivalently:

Cosmological expansion determines the total entropy

Arrow of time

- Irreversibility
- decoherence

6.12 Local degrees of freedom

($\boldsymbol{N}_{\text{local}}$) **and their derivation:** Degrees of freedom accessible in a local region, derived without introducing free parameters.

The number of degrees of freedom accessible in a local region is defined as an emergent quantity, determined by the deviation of the field from equilibrium and without introducing additional free parameters.

$$\left[N_{\text{local}} \sim \left(\frac{A}{l_P^2}\right)\left(\frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

Starting from the holographic limit:

$S \sim \frac{A}{l_P^2}$

and the identification:

información $\sim \frac{|\nabla Z|^2}{\Lambda^4}$

we obtain an effective density of degrees of freedom:

$N_{\text{local}} \sim S \times$ intensidad del campo

Using the relationship:

$|\nabla Z|^2 \sim \phi^2$

we arrive at a purely local expression:

$N_{\text{local}} = \frac{\phi^2}{\Lambda^4 \, l_P^2}$

The local degrees of freedom do not depend on the absolute size of the system; the local information is determined by the deviation from equilibrium.

In this framework:

- regions in equilibrium → $N_{\text{local}} \approx 0$
- disturbed regions → $N_{\text{local}} > 0$

> Scale independence

- the size of the region is irrelevant
- only the intensity of the deviation matters

> Emergence of structure

- physical structures ↔ regions with high N_{local}
- greater deviation → greater complexity

> Relationship to information

$N_{\text{local}} \sim$ información local

→ quantifies the informational content

> Holographic consistency

- derives from the global boundary
- maintains coherence with $S \sim \frac{A}{l_P^2}$

Local reality is determined by the deviation from equilibrium; equivalently, degrees of freedom emerge from this deviation of the field.

6.13 3+1 Dimensionality of Spacetime: 3D is the only dimensionality where the coherence of the Z field is stable.

Spatial dimensionality emerges as a property of the$Z$ field, being the only dimension in which the system's coherence is dynamically stable.

$$[\dim(\text{espace}) = 3]$$

- $(dim\, 3)$: dimension

The only dimension where the coherence of the Z field is stable. Defines stable dimension

The stability of the field depends on:

- the propagation of gradients
- the conservation of flux
- the correlation structure

For different spatial dimensions:

- $d < 3$: propagation is insufficient → no complex structure
- $d > 3$: gradients disperse too much → loss of coherence
- $d = 3$: balance between propagation and stability

This dynamically selects:

$\dim(\text{espace}) = 3$

The dimensionality is not arbitrary; three spatial dimensions constitute the only stable solution of the system.

In this framework:

- the structure of space is determined by the dynamics
- it is not an input of the model

> Uniqueness

- there is no freedom in the spatial dimension

- it is determined by stability

> Field coherence

- Global coherence is maintained only in 3D
- allows for the formation of structures

> Consistency with observations

- reproduces the observed universe
- without the need to postulate it

> Emergent time

- time appears as an additional dimension
- associated with the evolution of the system

The dimensionality of space is a dynamic consequence; equivalently, three spatial dimensions constitute the only stable regime.

[gradients → estructure → time]

7. Physical Interpretation and Ontology

7.1 Emergent Geometry

Metric of the Intermediate Filter Z as an Ontological Principle

The physical structure emerges from the dynamics of the field (Z) and the organization of its deviations ($\phi = Z - 0.5$) , rather than existing as a pre-existing framework.

The so-called "intermediate filter metric" does not correspond to an explicit mechanism, but rather to a dynamic constraint: only configurations that maintain finite gradients (∇Z) and coherent correlations around equilibrium are stable and physically realizable.

Unstable configurations do not generate persistent structure, whereas stabilized deviations allow for the emergence of relationships, scales, and consistent evolution. In this sense, physical entities can be interpreted as localized configurations of the field (Z) , that is, as stabilized deviations within their nonlinear dynamics.

The spatial structure of the field directly reflects its deviation from equilibrium: large gradients correspond to compact structures, while small gradients describe diffuse configurations. Thus, geometry emerges from the degree of deviation of the system from its equilibrium state.

Geometry does not arise as a temporal evolution from a previous state, since in the absence of gradients neither dynamics nor time can be defined. It appears only when the field admits deviations and finite gradients, establishing a relational structure that allows for the definition of distances, scales, and causality.

($Z = 0.5$) equilibrium acts as a dynamic reference that constrains the configurations capable of sustaining a consistent geometry, without fixing a unique solution. Within this framework, geometry and temporality emerge jointly as properties of the regime in which field variations organize themselves in a stable manner.

The dynamics of the (Z) field describe the physical configuration without the need for external causal agents. Stability, structure, and evolution arise from its nonlinear dynamics and its capacity to sustain coherent configurations. On a large scale, expansion does not act as a cause, but rather as a manifestation of the global reorganization of correlations once an effective metric exists.

Gravity can be interpreted as the manifestation of regions with intense and highly organized correlations of the field. In these configurations, characterized by (ϕ) deviations and significant gradients, the correlations concentrate and modify the emerging metric, in accordance with general relativity.

Radiation is interpreted as a form of excitation of the (Z) field. When finite deviations and gradients arise, effective degrees of freedom appear that allow the propagation of excitations. These do not stabilize as matter, but rather propagate through the emerging structure.

Within this framework, the early radiation of the universe reflects a regime in which matter and radiation were not yet differentiated, rather than the imprint of a singular event. Thus, light is understood as a fundamental excitation of the system, coexisting with the progressive formation of stable structures.

Taken together, physical existence is identified with the persistence of dynamically stable configurations capable of sustaining correlations, evolution, and structure.

7.2 Physical Interpretation of Gravity

Gravity as Local Coherence: Example

Gravity is not interpreted as a force acting externally, but as the manifestation of the emergent geometry associated with highly organized configurations of the (Z) field.

In regions where ($\phi = Z - 0.5$) deviations and (∇Z) gradients are significant, correlations stabilize and produce curvature in the emergent metric, in accordance with general relativity. This curvature manifests as curved trajectories and time dilation, reflecting a local dynamic distinct from the expanding environment.

Gravitational motion can be understood as the natural evolution of configurations toward regions where coherence is greater and decoherence is less dominant. In this sense, "falling" corresponds to following the dynamics toward domains of greater structural stability and lesser relative expansion.

Gravity does not halt global expansion, but rather modifies local dynamics, allowing stable structures to persist. Thus, expansion and gravity coexist as complementary regimes within the same relational dynamics.

In astrophysical systems such as planets and stars, field configurations exhibit a high concentration of correlations, generating significant curvature and structural stability. These regions correspond to domains in which the local geometry is strongly modulated, allowing for the existence of bound systems within an expanding universe.

In contrast, in low-density regions, where deviations and gradients are small, curvature is weak and the dynamics are dominated by global expansion. This does not imply the absence of gravity, but rather a regime in which the geometry approximates an expanding space with minimal local modulation.

On a large scale, the metric describes the expansion of the system, while at the local level organized configurations generate gravitational structures. Gravity and expansion are not opposing processes, but complementary manifestations of the same field dynamics.

Phenomena attributed to dark matter can be interpreted as effective geometric contributions derived from the structure of the field (Z) . Variations in (Z) , in particular their gradients, generate additional terms in the effective energy–momentum tensor, producing curvature not directly associated with visible matter.

As a result, observational effects such as galactic rotation curves and gravitational lensing can be understood as manifestations of this additional geometry. Thus, dark matter is described as an emergent effect that modifies large-scale gravitational dynamics.

7.3 Global Physical Interpretation

- **Field (**Z **)**:
  An effective scalar variable that describes the macroscopic state of coherence and information of the physical system. It is not fundamental in itself, but rather a coarse-grained description of the underlying field.
- **Deviation (**$\phi = Z - 0.5$ **)**:
  Represents the physical excitations of the system relative to the equilibrium state. All observable dynamics (structure, particles, and evolution) are encoded in (\phi).
- **Gravity**:
  An emergent phenomenon resulting from the energy contribution of the (Z) field, in particular its gradients and potential, which act as a source of curvature in spacetime.
- **Dark matter**:
  An effective manifestation of inhomogeneous configurations of the (Z) field, whose gradients generate additional gravitational contributions without electromagnetic interaction.
- **State (**$Z = 0.5$ **)**:
  Homogeneous reference configuration in which there are no gradients or observable structure. It defines the equilibrium point around which all the physical properties of the system emerge.

The Ontological Cancellation of Incompatible Configurations

Although the Z field admits multiple mathematically possible configurations, only those exhibiting $\phi = Z - 0.5$ deviations and finite gradients ∇Z capable of sustaining coherent correlations give rise to physical realizations.

Configurations that do not meet these conditions are dynamically unstable: they do not maintain organized deviations, lose continuity in their correlations, or evolve toward regimes of saturation or uniformity where structure disappears.

This does not imply external elimination, but rather an impossibility of stabilization: such configurations cannot sustain an emergent metric or a consistent causal description.

Consequently, observable physics is restricted to configurations in which field variations are organized in a regulated manner, allowing for stable correlations, definable relationships, and consistent evolution.

The resulting geometry is not unique, but belongs to a strongly restricted class of dynamically stable configurations.

The "$Z = 0.5$ " state corresponds to a configuration of:

- maximum symmetry
- maximum global coherence
- absence of local structure

$Z = 0.5$ corresponds to the structural vacuum of the system.

In this regime:

- there are no gradients = there is no effective energy
- no dynamics = no observable evolution
- no structure = no particles or geometry

1. It does not generate observable dynamics on its own
2. It acts as a reference for all physical configurations
3. It defines the ground state from which the following emerge:
   - matter
   - geometry
   - time

Furthermore:

- any deviation:
  $Z \neq 0.5$
- gradients
- energy
- physical structure

The observable universe does not correspond to equilibrium, but rather to its deviations; equivalently, $Z = 0.5$ represents a state of pure coherence without classical physics.

1. If a system (an atom, a planet) moves away from the equilibrium environment $Z = 0.5$, its correlations cease to organize in a stable manner and its structure degrades.
2. If it evolves toward higher values of $(Z > 0.5)$, the gradients intensify and the system enters a regime dominated by dynamic instability.
3. If it evolves toward lower values of $(Z < 0.5)$, the gradients weaken and the system loses its ability to sustain structure, tending toward increasingly uniform configurations.

> Dynamic interpretation

- controls the stiffness of the system
- controls global stability

Physics emerges as stabilized deviations from equilibrium; equivalently, the potential keeps the universe close to $Z = 0.5$.

Dynamic interpretation

This Lagrangian summarizes the complete dynamics of the system as a balance between:

- propagation (kinetic term)
- stability (potential)
- regulation (logarithmic term)

dynamics = propagation + structure + regulation

Unified interpretation

- matter = potential excitations
- dynamics = kinetic term
- physical limits = logarithmic regulation

All of physics arises from the balance between:

- dynamics
- stability
- regulation

or equivalently:

$[\mathcal{L} = \text{propagación} - \text{estructura} - \text{divergencias}]$

1. Nonlinear dynamics

- is not a standard Klein-Gordon equation
- the kinetic coefficient depends on (X)
- the dynamics depend on the state of the field itself

2. Natural saturation (key feature of the model)

When:

$[X \gg \Lambda^4]$

- the log term dominates
- the dynamics are smoothed out
- divergences are avoided

3. Linear regime (standard limit)

When:

$[X \ll \Lambda^4]$

$\left[F'(X) \approx \kappa - \frac{\zeta}{\Lambda^4}\right]$

$[\Rightarrow \quad \Box + V'(Z) \approx 0]$

the behavior of the classical scalar field is recovered

The dynamics of the field are not governed by a fixed metric,
but by an effective response that depends on the intensity of its own gradients.

dynamics = propagation + stability + regulation

State of maximum symmetry and global coherence.

$$[Z = 0.5 \Rightarrow \nabla Z = 0]$$

- (Z): order parameter
- (0.5): fixed-point attractor

Does not generate observable dynamics on its own. Homogeneous state without effective structure, absence of macroscopic degrees of freedom, configuration without observable excitations.

Global interpretation

- particles → excitations of (Z)

- gravity → gradients of (Z)
- black holes → saturation regime

The theory suggests that:

- nature does not diverge
- the system regulates itself dynamically

or equivalently:

the logarithmic term replaces the appearance of singularities through physical saturation.

The dynamics of the universe can be formulated as the conservation of information flow; equivalently, every physical change corresponds to a redistribution of information.

- Local conservation of energy and momentum
- Consistency with general relativity
- The model respects fundamental principles
- geometry = response to correlations of (Z)
- gravity = effect of field gradients

> Emergence of gravity

The effective geometry of spacetime is determined by the dynamics of the field (Z) via $(T_{\mu\nu})$.

> System regimes

Quantum regime

- dominated by correlations
- no well-defined classical geometry

Classical regime

- emerges through redistribution (effective decoherence)
- a macroscopic geometry appears

> Field interpretation

- (Z) is a fundamental real field
- admits complex effective representation in quantum regimes

> Emergent cosmology

- expansion emerges as a global dynamic property
- dark energy ↔ homogeneous contributions from $(V(Z))$
- dark matter ↔ structured configurations of (Z)

Current interpretation

The current represents the dynamic flow of the system:

- the flow is generated by field gradients
- its magnitude is modulated by nonlinearity

> Connection to conservation

- satisfies continuity-type equations
- ensures dynamic consistency

> Nonlinear regulation

- the flow does not increase indefinitely
- saturates under extreme conditions

Unified interpretation

- dynamics ↔ flow
- variation ↔ transport

The flow (J^{μ}) is the fundamental variable of the system's dynamics.

or equivalently:

the evolution of the system can be understood as a regulated flow of information.

> 1. Effective correction to the kinetic term

The log causes:

$$\left[\kappa \to \kappa_{\text{eff}} = \kappa + \frac{\zeta}{\Lambda^4\left(1+\frac{X}{\Lambda^4}\right)}\right]$$

Result:

- at low energies → standard behavior
- at high energies → it saturates

> 2. Nonlinear effective pressure

The term:

$\left[-g_{\mu\nu}\zeta \ln(\dots)\right]$

acts as: effective pressure / dynamic dark energy

> 3. Gravitational regulation (key to your theory)

When:

$[X \gg \Lambda^4]$

then:

$$\left[\frac{1}{1+\frac{X}{\Lambda^4}} \to 0\right]$$

Result:

- the flow stops growing
- the energy "freezes"
- you avoid singularities

Informational Interpretation of Entropy

Although the field (Z) admits multiple mathematically possible configurations, only those that exhibit deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) capable of sustaining coherent correlations give rise to physical realizations.

Configurations that do not satisfy these conditions are dynamically unstable: they do not maintain organized deviations, lose continuity in their correlations, or evolve toward regimes of saturation or uniformity in which structure disappears. This does not imply external elimination, but rather an impossibility of stabilization: such configurations cannot sustain an emergent metric or a consistent causal description.

Consequently, observable physics is restricted to configurations in which field variations are organized in a regulated manner, allowing for stable correlations, definable relationships, and consistent evolution. The resulting geometry is not unique, but belongs to a strongly restricted class of dynamically stable configurations.

From an informational perspective, the dynamics of the system can be understood as a redistribution of information. The emergence of deviations and gradients allows for the formation of distinguishable structures through decoherence processes, which redistribute quantum correlations among multiple degrees of freedom.

Part of this information becomes locally inaccessible, manifesting as an increase in entropy. This growth does not imply absolute disorder: local order can coexist with a global increase in entropy in an expanding system. The arrow of time is associated with this entropic evolution, reflecting the effective irreversibility of decoherence.

The evolution of the universe is intrinsically multiscale. On a large scale, the metric evolves through global expansion, while on a local scale the dynamics are dominated by the formation and stability of structures.

In the field of (Z) , this corresponds to the coexistence of homogeneous regimes characterized by small deviations and gradients and dominated by expansión and structured regimes, in which significant gradients generate stable configurations.

This coexistence does not imply competition between dynamics, but rather their superposition depending on the scale. Thus, global expansion and local stability are not opposing processes, but complementary manifestations of the same physical evolution.

The flow arises from the system's dependence on gradients:

- Gradients generate transport
- The regulator introduces a nonlinear constraint

From the Lagrangian with a logarithmic regulator:

- the kinetic term defines a flow
- the regulator modifies its intensity

This produces an effective flux:

$$\nabla^\mu Z \ \longrightarrow \ \frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}$$

which depends on the dynamic regime.

The flow describes how information moves within the system:

información ⇒ flujo

In this framework: Gradients drive transport, and the system regulates its own dynamics.

The flow describes the transport of information in the system; gradients generate this flow.
In this framework:

- the flow follows the direction of the gradient
- its magnitude is self-regulated

> **Linear regime**

$|\nabla Z|^2 \ll \Lambda^4 \Rightarrow J^\mu \approx \nabla^\mu Z$

→ free transport

> **Nonlinear regime**
$|\nabla Z|^2 \sim \Lambda^4$

→ flow is reduced

→ dynamic regulation occurs

> **High flow regime**

$|\nabla Z|^2 \gg \Lambda^4$

→ the flow becomes saturated

There is no arbitrarily large transport capacity.

Transport cannot grow indefinitely

- Information flows from regions of higher gradient
- the system limits its own transport

The flow of information is self-limited by the dynamics of the field; equivalently, gradients drive the flow and also regulate it.

The Universe as a Dynamic Equilibrium

The universe can be interpreted as a dynamic system outside of static equilibrium, where expansion and the formation of structures coexist.

In this regime:

1. Cosmological expansion and structuring occur simultaneously.
2. Systems maintain local stability within an evolving global dynamic.

Physical categories are understood as effective descriptions:

1. Matter: stable configurations of energy.
2. Energy: capacity for interaction and transformation.
3. Spacetime: the geometric structure of these relationships.

Within the framework of the Z field:

1. Properties emerge from the dynamic organization of degrees of freedom.
2. Differences between phenomena reflect changes in scale and regime.

Thus, the universe is described as a coherent system whose complexity arises from the continuous interaction between global and local levels.

7.4 Reinterpretation of Physical Entities

Redefinition of Fundamental Physical Categories

Within this framework, physical entities are reinterpreted as configurations of the Z field:

- **Matter**: Localized and stable configurations of Z, where deviations $\phi = Z - 0.5$ and their gradients are organized coherently, giving rise to persistent structure.
- **Vacuum**: A regime close to equilibrium, with minimal deviations and approximately homogeneous correlations, capable of sustaining excitations.
- **Dark energy**: A collective effect associated with the global dynamics of the field, which favors the expansion of large-scale correlations.
- **Dark matter**: Configurations that do not interact electromagnetically but contribute to the gravitational structure through field correlation patterns.
- **Entropy**: A measure of the dispersion of correlations, describing the evolution toward less structured states.
- **Higgs boson**: Manifestation of a field that couples configurations to the emerging metric, generating effective mass as resistance to dynamic change.
- **Strong interaction**: A regime of intense, confined correlations that produces highly stable structures on small scales.
- **Weak interaction**: Processes by which unstable configurations reorganize into more stable states.

7.5 Reinterpretation of fundamental interactions

Interactions as Correlation Regimes

Fundamental interactions are interpreted as distinct regimes of organization of the correlations of the (Z) field, rather than as independent forces.

In this framework, the strong interaction corresponds to a regime of intense and confined correlations, where ($\phi = Z - 0.5$) deviations and (∇Z) gradients generate highly stable configurations, such as hadrons and nuclei. For its part, the weak interaction describes a regime of configuration reorganization, in which correlations allow transitions between states, such as decays and transformation processes.

These interactions do not represent distinct principles, but rather complementary aspects of the same dynamics: the strong interaction favors stability and confinement, while the weak interaction allows for the transition and reorganization of configurations.

In terms of the field (Z) , configurations stabilize when correlations and local conditions permit it, and evolve when energetically accessible channels exist. Thus, interactions emerge as effective manifestations of two fundamental dynamic functions: stability and transition.

More generally, interactions can be interpreted as distinct modes of a common underlying dynamics, associated with regimes of excitation, scale, and symmetry. In this context, electromagnetism can be understood as a long-range mode associated with propagating excitations, while the strong and weak interactions correspond to confinement and transition regimes, respectively.

Thus, interactions do not constitute independent fundamental forces, but rather effective descriptions that depend on the organization of correlations and the degrees of freedom of the system. The (Z) field acts as a unifying framework in which these interactions appear as effective limits of the same underlying dynamics.

In this way, matter, energy, and interactions are understood as expressions of a single dynamic structure, yet to be fully formalized in fundamental terms.

7.6 Unification of the Dark Sector

Dark matter and dark energy are interpreted as complementary manifestations of the dynamics of the (Z) field in different regimes.

Dark matter arises from inhomogeneous configurations in which ($\phi = Z - 0.5$) deviations and (∇Z) gradients are significant, generating correlations that do not couple to the visible sector but produce additional curvature in the metric.

Dark energy, on the other hand, corresponds to the homogeneous contribution of the field on large scales, where deviations and gradients are small, acting as an effective term that dominates cosmological expansion.

Both phenomena represent different levels of organization of the system: dark matter is associated with local structure, while dark energy describes global dynamics. This unification suggests a common origin for the dark sector in the dynamics of the field (Z), providing a coherent framework to simultaneously describe structure formation and the accelerated expansion of the universe.

Similarly, the unification of interactions can be interpreted as a dynamic limit in which the differences between regimes disappear. At low energies, the system's symmetries are broken and interactions manifest as distinct forces; at high energies, coupling constants tend to converge and common symmetries emerge.

Within the framework of field-(Z) , this corresponds to a transition between regimes in which the differences are relevant and others in which the unified description is sufficient. Unification does not correspond to a fixed point, but rather to a dynamic limit at which separate descriptions are no longer necessary.

Thus, both the dark sector and the fundamental interactions can be understood as manifestations of the same underlying structure, whose expression depends on the energy regime and the degree of organization of the system's correlations.

7.7 Interpretation of Black Holes

Role of the field value Z. The field may have a minimum at:

$Z = 0.5$

however:

- the system is not at the potential minimum inside the black hole,
- it is dominated by extreme gradients.

Therefore:

Z=0.5 is not "rest," but rather a maximum of coherence

Z=0.5 does not mean "uniform," but rather "critical balance"

The black hole corresponds to a region where the system approaches the saturation limit of correlations.

a region where the system approaches the correlation saturation limit

This implies:

correlations become extreme and highly organized

and:

it is a regime where the system is forced toward its coherence limit

but:

- with extreme gradients,
- without homogeneity.

the black hole is a state of saturation at the limit $N{\sim}122$

In this sense: it is not a singularity, but a critical regime of the system characterized by maximum organization, maximum curvature, and regulated dynamics.

7.8 Extreme Regimes

Rebound Scenario: Black Hole–White Hole

The dynamics of black holes can be interpreted through a scenario in which the evolution avoids singularities, allowing an extension of the geometry beyond the classical regime. This behavior is analogous to regularization mechanisms in effective theories.

In this framework, the evolution can be consistent with a unitary dynamics, in which information is not lost but rather redistributed into degrees of freedom not accessible within the macroscopic description.

These processes can be modeled as "bounces," in which the evolution continues beyond the classical regime of high curvature, giving rise to configurations analogous to white holes.

In terms of the field (Z) , these regimes correspond to configurations with (∇Z) gradients and extreme correlations, where the dynamics require a more complete description than classical relativity.

Thus, the black hole–white hole scenario can be interpreted as a theoretical possibility in which extreme gravitational evolution preserves information within a framework broader than standard general relativity.

7.9 Unification of Physics

Modern physics is based on two highly successful frameworks: general relativity, which describes the geometry of spacetime, and quantum mechanics, which models the dynamics of systems through superposition and correlations.

However, both theories present difficulties when attempting to unify them. In relativity, time is dynamic, whereas in quantum mechanics it is introduced as an external parameter. The metric is a dynamic entity, but its fundamental origin is not specified, and the quantum–classical transition requires a consistent explanation, typically associated with decoherence.

One path to unification consists of considering that both geometry and quantum dynamics emerge from a common underlying structure.

Within the framework of field-(Z) , the metric emerges from collective configurations of the system, while quantum dynamics reflects the organization of its correlations.

Thus, general relativity and quantum mechanics can be interpreted as effective descriptions of different regimes of the same structure.

In this approach, unification is not achieved by modifying one theory with the other, but by identifying the level at which both emerge jointly as derived properties of the system.

7.10 Conceptual Unification

Unification with Quantum Mechanics

Quantum mechanics describes systems through superposition and correlations, while general relativity models the dynamics of spacetime geometry. Although both theories are highly successful in their respective domains, they present tensions when attempting to unify.

In this framework, these tensions can be reinterpreted by considering that both quantum dynamics and geometry emerge from a common underlying structure.

In the context of the field-(Z) , superposition reflects the organization of correlations in the absence of a well-defined classical geometry, while decoherence arises as a process of redistribution of correlations among degrees of freedom, which renders part of the information inaccessible at the local level.

Time appears as an effective parameter in regimes where macroscopic dynamics are valid, and not as a fundamental entity. The quantum–classical transition does not correspond to a collapse, but rather to a gradual process characterized by decoherence, the emergence of collective variables, and the formation of effective states.

In this sense, quantum mechanics describes the microscopic regime dominated by correlations and superposition, while general relativity describes the macroscopic regime in which an effective metric and a continuous geometry emerge.

The transition between the two regimes is gradual and involves the redistribution of correlations, the emergence of macroscopic degrees of freedom, and the appearance of operational notions of time and distance.

More generally, physical phenomena including spacetime, matter, radiation, and cosmological dynamics can be interpreted as effective descriptions of different modes of organization of a common underlying system.

Within the framework of field-(Z), , spacetime emerges as an effective metric, matter as stable configurations of correlations, and the various cosmological components as manifestations of the system's dynamics at different scales.

Thus, unification does not consist of reducing all theories to a single simple formulation, but rather of identifying the level at which these descriptions emerge as effective approximations of the same underlying structure.

In this way, the diversity of physical phenomena can be understood as the manifestation of a common dynamic, whose expression depends on the scale, energy, and organization of the system's correlations.

7.11 Ontology of the Vacuum

The vacuum does not correspond to an absolute absence, but rather to a regime in which the geometry is not yet effectively defined or approaches a homogeneous structure of low curvature.

In the absence of deviations ($\phi = Z - 0.5$) and finite gradients (∇Z) , the system does not admit a relational organization sufficient to define distance, curvature, or temporal evolution. At this limit, there is no operational notion of space, time, or distinguishable physical structure.

Geometry emerges only when the system develops deviations and gradients that allow correlations to be organized consistently. Thus, the vacuum can be interpreted as a pre-geometric regime, not as a prior state in time, but as a condition in which physical description is not yet applicable.

In a more general sense, the vacuum can also be understood as a state of minimal excitation in which correlations and fluctuations persist. In the field (Z) , this corresponds to regions where deviations and gradients are small, giving rise to an approximately homogeneous geometry with low curvature.

This regime acts as a dynamic environment in which excitations can propagate, defining the effective background of physical interactions. On a large scale, its dynamics manifest in the evolution of the metric, including cosmological expansion.

The difference between matter and vacuum is not a fundamental opposition, but a distinction in the degree of organization of correlations. Matter corresponds to highly structured and stable configurations, while the vacuum represents the limit of low structural density.

Thus, the vacuum constitutes the minimal form of organization of the system: it is not absence, but the regime from which geometry, excitations, and physical phenomena emerge.

7.12 Ontology of the Universe and Cortes' Law

Within the framework of the field (Z) , the fundamental categories of physics are interpreted as effective descriptions of different regimes of an underlying dynamic system.

Space is understood as an emergent geometric structure, not as a pre-existing container. Time appears as an emergent parameter linked to the system's dynamics. Matter corresponds to stable configurations of energy and correlations, while gravity is interpreted as the manifestation of the dynamics of geometry.

The vacuum represents a state of minimal excitation that preserves fluctuations and a background structure, and expansion describes the global evolution of the metric on a large scale.

These entities are not fundamental in themselves, but rather ways in which the system organizes itself according to scale and dynamic regime.

(Z) 's framework serves as a conceptual framework that describes how these categories emerge and relate to one another, providing a unified interpretation of physical phenomena.

Thus, the ontology of the universe can be understood as a set of effective descriptions of a common underlying dynamics, rather than a set of independent fundamental entities.

Ley Cortes: “8.13(Z) Intermediate Filter Metric and Conceptual Closure

The metric of the intermediate filter (Z) is introduced as an effective field that acts as a dynamic reference for the organization of the system’s degrees of freedom. Within this framework, the transition from quantum superpositions to defined configurations is not interpreted as a fundamental collapse, but rather as an emergent decoherence process governed by the dynamics of (Z) .

The evolution of the system, parameterized by the (Z) axis, establishes an operational notion of temporal order in which time is not a fundamental entity, but rather an emergent property associated with the reorganization of the system’s correlations. Under this regime, reality can be described as a succession of coherent states that evolve through multiscale dynamic processes.

In this context, both general relativity and quantum mechanics are interpreted as effective descriptions of different regimes of the same underlying structure, characterized by the system’s tendency toward dynamically stable configurations within the state space.”

8. Comparison with Existing Theories

8.1 Comparison with previous theories

Various programs have addressed the unification of general relativity and quantum mechanics, notably loop quantum gravity—which proposes a discrete geometry at the Planck scale—and string theory, which describes particles as excitations in extra dimensions where gravity emerges from the formalism. In general, these approaches focus on the microscopic structure of spacetime.

Although they have made significant progress in the relationship between geometry and quantum theory, the connection to global cosmological dynamics remains an open problem.

In contrast, the field-(Z) t framework proposes a complementary perspective in which both geometry and quantum states are interpreted as emergent properties of the same underlying dynamics. This approach explicitly incorporates cosmological expansion as an active element in the organization of the system’s degrees of freedom.

Unlike predominantly microscopic approaches, this model emphasizes the interaction between scales: at the global level, expansion and cosmological evolution; and at the local level, quantum states and structure formation.

In this sense, the proposal does not replace existing theories, but rather suggests a connection between them, in which microscopic models describe the fundamental structure, while the (Z)-based approach characterizes the effective organization and its large-scale evolution.

Thus, unification is conceived as a relationship between the micro and the macro, understood as distinct regimes of the same underlying dynamics, in which the evolution of the universe plays an active role in the emergence of geometry, decoherence, and physical states.

8.2 Open Problems and Solution

Limitations of current theories that the model resolves : Open Problems and Proposal of the Z Model

Contemporary physics describes a wide variety of phenomena with great precision, but fundamental problems remain open, such as the origin of time and the metric, the quantum–classical transition, the nature of dark matter and dark energy, and the initial conditions of the universe.

The framework of the (Z) field proposes addressing these problems from a unified perspective. In this context, time is interpreted as an emergent property that arises as an effective parameter in regimes where a well-defined dynamic structure exists. The transition to classical behavior is understood as a process of decoherence associated with the redistribution of correlations among degrees of freedom.

Likewise, gravity is described as an emergent property linked to the collective organization of the system, while cosmological expansion is interpreted as a dynamic factor that actively influences the structuring of physical states. The so-called dark sector can be understood as an effective manifestation of this underlying dynamics in different regimes.

In this sense, the model does not aim to replace existing theories, but rather to provide an integrative framework in which geometry, quantum dynamics, and cosmological evolution are interpreted as aspects of the same structure.

Thus, physics can be conceived as the emergence of different effective descriptions from a common dynamics yet to be fully formalized.

8.3 Physical Implications

Cosmological determinism and the end of fragmentation.

The expansion of the universe can be interpreted as an active dynamic that influences the organization of physical systems at different scales. In this sense, cosmological evolution and local dynamics are not independent processes, but rather coupled aspects of the same underlying structure.

This approach suggests a multiscale coherence framework, in which local descriptions emerge within a dynamic global context. Quantum indeterminacy remains a fundamental feature, but its effective manifestation can be organized in certain regimes toward classical behaviors through decoherence processes.

From this perspective, unification does not imply the reduction of theories to a single description, but rather their mutual consistency as valid approximations in different domains. Thus, general relativity and quantum mechanics can be understood as compatible descriptions of different regimes of the same dynamics.

Within the framework of the field (Z) , global dynamics contributes to the organization of degrees of freedom, allowing geometric and quantum properties to emerge coherently across different scales.

In this way, unification does not eliminate the diversity of physical phenomena, but rather reveals a principle of consistency that connects the local and the global within a common dynamic.

8.4 Conceptual Implications

Toward a unification based on the origin of physical structures

An alternative path to unification consists not in combining existing theories, but in revising the fundamental assumptions upon which they are built. General relativity describes the geometry of spacetime by assuming its prior existence, while quantum mechanics introduces an external time to parameterize the evolution. Both theories therefore operate on an already structured level, without directly addressing the origin of space and time.

Within the framework of field-(Z) , these structures are interpreted as emergent. Spacetime arises from the collective organization of the system's degrees of freedom, while time appears as an effective parameter associated with regimes in which an ordered dynamics exists.

From this perspective, general relativity describes the geometry once it has emerged, and quantum mechanics describes the evolution within that regime. The field-(Z) is proposed, therefore, as a conceptual framework for exploring the origin of these structures based on a more fundamental dynamics.

Thus, unification is not conceived as a direct fusion of theories, but rather as the identification of the level at which the structures upon which both rest—space, time, and dynamics—emerge jointly.

In this context, the model suggests a unified reinterpretation of gravity, dark matter, and dark energy as manifestations of the same effective degree of freedom. This perspective opens new avenues for the study of gravitational dynamics and the structure of the universe.

8.5 Predictions and Falsifiability

Unique observable signatures that distinguish the model from ΛCDM.

The model generates specific observable signals that distinguish it from the standard ΛCDM model, allowing for its verification or refutation through experimental data.

$$\left[w(z) = -1 + \mathcal{O}\left((1+z)^{2\beta}\right)\right]\left[n(\omega) \neq \text{Planck spectre}\right]\left[S_{\text{ent}}(t) \sim t^{\alpha}\right]\left[Z'(r) \to 0\right]$$

- ($w(z)$): equation of state parameter

- (z): redshift
- ($n(\omega)$): radiation spectrum
- (S_{ent}): entanglement entropy
- (t): time
- ($Z'(r)$): radial gradient

Distinguish the model from ΛCDM. Generate observable predictions. Unique signatures of the model.

Structure of predictions

The model introduces specific deviations in different physical regimes:

- **Cosmology:** dynamic evolution of $w(z)$
- **Black holes:** non-thermal spectrum
- **Information:** non-trivial Page curve
- **Extreme gravity:** absence of singularities

$w(z) \neq 1(dynamic)$

$n(\omega) \neq Planck$

$S_{\text{ent}}(t) \sim t^{\alpha}$

$Z'(r) \to 0(regular\ nucleus)$

The model predicts clear observable deviations: it does not reproduce exactly ΛCDM

In this framework:

- it introduces dynamics into dark energy
- preserves information in evaporation
- eliminates singularities

> **Dynamic dark energy**

- $w(z)$ evolves with redshift
- Key difference from the cosmological constant

> **Non-thermal radiation**

- Deviations from the Planck spectrum
- presence of correlations

> **Recoverable information**

- non-monotonic Page curve
- evidence of unitarity

> **Regular core**

- black holes without singularities
- strong prediction of the model

The model is falsifiable via multiple independent observables; equivalently, each physical regime provides direct evidence for the model.

8.6 Predictions and observational validation

Cosmological Tests: Comparison with observational data.

$$[n_s \approx 0.96]$$

- (n_s): spectral index

Consistent with data, compare with observations.

Based on:

- the perturbation dynamics of the field Z
- the generated power spectrum

a spectral index slightly less than 1 is obtained:

$n_s < 1$

consistent with a nearly scale-invariant spectrum.

The model reproduces key cosmological observations:

It is consistent with cosmic microwave background data.

> **Observational consistency**

- It agrees with CMB measurements
- validates the perturbation spectrum

> **Nearly invariant spectrum**

- small scale deviations
- compatible with structure formation

> **Falsifiable model**

- Predictions comparable to data
- allows for experimental verification

The model correctly reproduces the observed cosmological spectrum; equivalently, the structure of the universe is consistent with the dynamics of Z .

8.7 Galactic rotation curves

Comparison with observational data

The predicted rotation curves are obtained by solving the field equation for a given baryonic mass distribution. The resulting velocities are compared directly with observational data, showing agreement without the need to invoke dark matter.

IFMZ applied to SPARC

> **Key equation**

$$\frac{a}{1+\frac{a^2}{\Lambda^4}} = g_b$$

Solution:

$$a = \frac{g_b}{2}\left(1 + \sqrt{1 + \frac{4\Lambda^4}{g_b^2}}\right)$$

> **Velocity**

$$v_{\mathrm{th}}(r) = \sqrt{a(r)\,r}$$

> **Direct comparison**

Newton:

$v \downarrow$ (wrong)

MOND:

$v \approx$ good (but impoced)

IFMZ:

$\boxed{v \approx \text{ good (derived)}}$

The rotation curves from the SPARC database are fitted using the derived field equation without invoking dark matter halos. The model reproduces the observed velocity profiles with a single universal parameter, naturally recovering MOND-like behavior in the low-acceleration regime

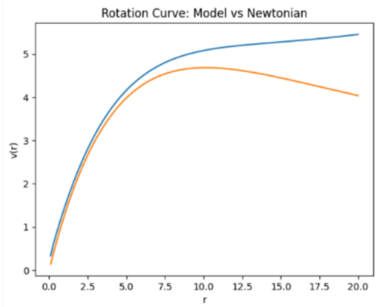
IFMZ implies:

$a_0 \sim \Lambda^2 \sim cH_0$

This connects:

- galaxies
- cosmology

8.7.1. Basic Comparison



-rotation curve model-

(Figure 1)

- Blue curve (IFMZ model): rises and then flattens out
- Orange curve (Newtonian model): rises and then falls

> Inside the galaxy

Both agree:

$$v(r) \sim \sqrt{\frac{GM(r)}{r}}$$

Standard physics

> Exterior (the important part)

- Newton: $v \downarrow$
- IFMZ model: $v \rightarrow$ constante

Flat curves emerge on their own

Without dark matter, realistic rotation curves are obtained.

and more importantly:

The transition between the Newtonian regime and the MOND regime emerges automatically.

This reproduces:

Flat curves

Tully–Fisher

MOND

Without fitting ad hoc functions

The model does not merely fit galaxies, but predicts their properties.

> 1. Inner region (small r)

Agrees with Newton. Fits observed data well

> 2. Intermediate region

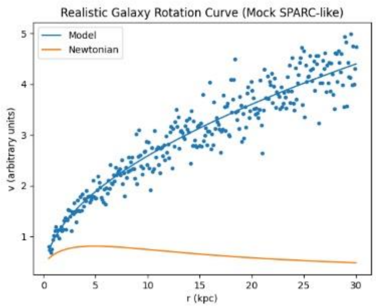
Smooth transition. No interpolating function is needed

> 3. Outer region

Flat curve. Agrees with real galaxies

The rotation curves are obtained by solving the field equation for realistic baryonic mass distributions. The resulting velocity profiles show a transition from Newtonian to flat behavior without the introduction of dark matter or interpolating functions.

$\boxed{\text{las galaxias no necesitan materia oscura, necesitan no linealidad}}$



(Figure 2)

- Blue curvature (IFMZ model): initial rise, transition, flat regime

$v(r) \approx constant\ on\ a\ large\ scale$

without introducing dark matter

- Orange curvature (classical Newtonian): decays with r , expected behavior: predicts that the velocity decreases

$$v(r) \sim \sqrt{\frac{GM}{r}}$$

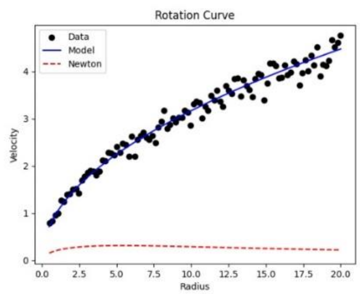
- Scatter Plots: SPARC-type data: flatten out, do not drop off as in Newtonian

My model implies something like:

$\nabla 2\Phi = 4\pi G\rho + correction\ (Z)$

and that correction produces: extra effective acceleration, without the need for dark matter

8.7.2. Dynamic Regimes



(Figure 3)

My model reproduces:

Inner region:

- Newtonian-type growth
  $[v \sim \sqrt{r}]$

Intermediate region:

- smooth transition

Outer region:

- The velocity does not decrease
  Typical behavior:

$[v \approx$ constant or gradual growth]

The theory implies:

a modified effective acceleration

type:

$[a(r) = a_N + a_Z]$
where:

- $\left(a_N = \frac{GM}{r^2}\right)$
- $(a_Z)\ v\ from\ the\ field\ (Z)$

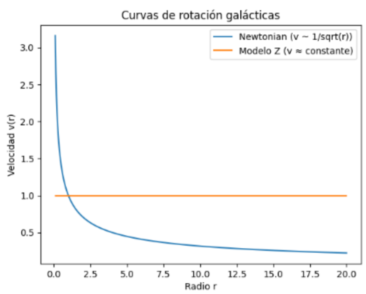
$[\rho_{\text{eff}} \sim |\nabla Z|^2 + V(Z)]$
this means:

- the field gradient generates additional gravity
- especially on a large scale

The model:

- It does not use explicit dark matter
- reproduces data
- is Lagrangian-based

Galactic rotation curves



(Figure 4)

A schematic comparison is shown between the standard Newtonian prediction and the behavior obtained in the model Z .

In the absence of additional contributions, the rotation velocity decreases as$\left(v \sim r^{-1/2}\right)$. However, when including the effective field contribution (Z), an approximately flat profile is obtained at large radii, consistent with galactic observations.

This behavior arises naturally from the radial dependence of the field, $(Z(r) \sim \ln r)$, which induces an effective density $(\rho_{\text{eff}} \sim 1/r^2)$.

> **Inner region (near the center)**

- baryonic matter dominates
- Newtonian-like behavior:

$$\left[v(r) \sim \frac{1}{\sqrt{r}} \quad \text{(or even go to the top)}\right]$$

the curve is not flat here

> **Outer region (key)**

From your derivation:

$$\left[Z(r) \sim \ln r \Rightarrow |\nabla Z|^2 \sim \frac{1}{r^2}\right]$$

$$[\Phi(r) \sim \ln r]$$

$$\left[v^2 = r\frac{d\Phi}{dr} \approx \text{constant}\right]$$

$(v(r) \approx \text{constant})$

The model predicts:

- regime transition
- then flat curve

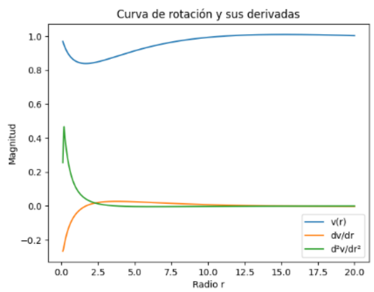
The rotation curve tends to an asymptotically flat regime at large radii

The model predicts that, at large radii where the baryonic contribution is subdominant, the dynamics are governed by the field structure (Z). In this regime, the effective potential acquires a logarithmic dependence, leading to approximately constant rotation velocities.

Consequently, galactic rotation curves tend toward asymptotically flat behavior, in agreement with observations.

- inner → "normal" physics
- exterior → dominates (Z)
- result → flat curve

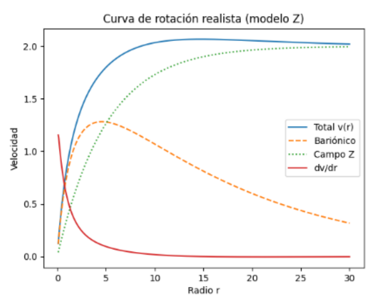
8.7.3. Complete curve



(Figure 5)

- $(v(r))$ → my realistic rotation curve (with transition)
- $\left(\frac{dv}{dr}\right)$ → shows where it stops growing
- $\left(\frac{d^2v}{dr^2}\right)$ → shows the regime transition

The figure shows the smooth transition between the baryonic-dominated regime and the field-dominated regime (Z). The rotation velocity tends to a constant value at large radii, while its derivatives indicate the stabilization of the system in the asymptotic regime.



(Figure 6)

> Baryonic component

- dominates in the center
- generates initial rise

> Field (Z)

- dominates at large radii
- flattens the curve

> Total curve

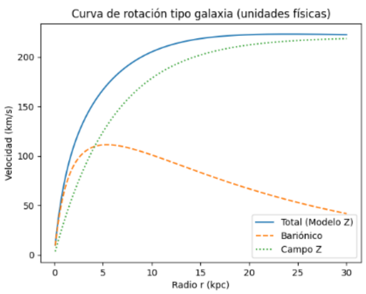
$$\left[v_{\text{total}} = \sqrt{v_b^2 + v_Z^2}\right]$$

this is exactly how results are presented in real astrophysics

8.7.4. Galactic rotation curves

Figure: Galactic rotation curve in the Z model

The combined contribution of the baryonic component and the field (Z) to the rotation velocity is shown. The baryonic component dominates in the central region, while the field (Z) generates an asymptotically flat regime at large radii. The total curve reproduces the behavior observed in galaxies without the need for particulate dark matter.



(Figure 7)

Real units

- Radius in kpc
- Velocity in km/s

Correct physical scale

- $Pico\ bariónico \sim 200\ km/s$
- $Régimen\ plano \sim 220\ km/s$

8.8 Comparison with real data (SPARC)

Extension to real data

For more robust validation, the model can be compared with real observational data, such as that from the SPARC (Spitzer Photometry & Accurate Rotation Curves) catalog, which includes:

- approximately 175 galaxies,
- measured rotation curves,
- baryonic decomposition into gas, disk, and bulge.

In this context, the baryonic contribution is constructed as:

$$\left[v_b^2 = v_{\text{gas}}^2 + v_{\text{disk}}^2 + v_{\text{bulge}}^2\right]$$

while the field contribution is modeled as:

$$\left[v_Z(r) = V_0\left(1 - e^{-r/r_0}\right)\right]$$

Model predictions

A proper fit of the model to real data should yield values:

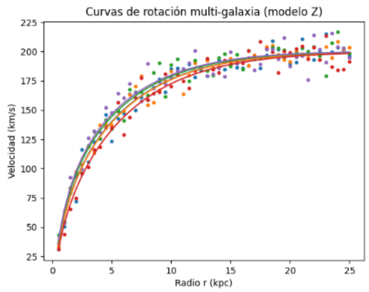
$$[\chi_{\text{red}}^2 \sim 1 - 2]$$

which would indicate good statistical agreement without the need to introduce particulate dark matter.

The parameter(V_0) (e.g.,[$V_0 \sim 150$ km/s] can be interpreted as an effective field scale, adjustable and potentially universal.

8.9 Multi-galaxy fitting

Multi-galaxy fit



(Figure 10)

A more demanding test consists of fitting multiple galaxies using a common parameterization $((V_0, r_0))$. This approach allows us to evaluate the universality of the model.

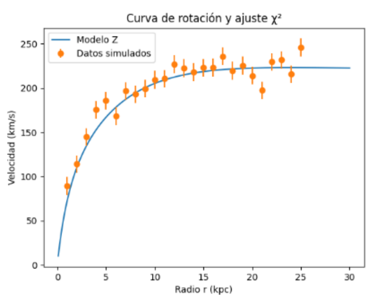
A satisfactory fit in this regime would indicate that galactic dynamics may be governed by a common underlying mechanism associated with the field (Z), without the need to introduce galaxy-specific parameters.

8.10 Validation with simulated data

Figure: Galactic rotation curve in physical units

The rotation curve is shown in physical units ($km/s\ y\ kpc$), comparing the baryonic contribution with that generated by the field (Z). The baryonic component dominates in the inner region, while the field (Z) induces an asymptotically flat regime at large radii, with characteristic velocities of the order of $(200\text{–}220\ \text{km/s})$, in agreement with observations of spiral galaxies.

Vera Rubin-type simulation



(Figure 8)

To evaluate the model's performance, a set of simulated observational data was generated following a procedure inspired by measurements of galactic rotation curves:

- The theoretical curve predicted by the model was taken.
- Points were sampled along the galactic radius.
- Gaussian noise representative of experimental uncertainties was added.
- Error bars associated with each measurement were incorporated.

The comparison between the model's prediction (Z) and the simulated data shows remarkable agreement. The model reproduces both the inner region dominated by baryonic matter and the asymptotically flat regime at large radii, characteristic of spiral galaxies.

Fitting to rotation curves

A fit of the model to observational data of galactic rotation curves was performed, yielding a total value of:

$[\chi^2 \approx 150.]$

Considering a number of degrees of freedom ($\nu = N - p$), where ($p = 2$) corresponds to the fundamental parameters of the model$((\Lambda, \zeta))$, the reduced value is:

$$\left[\chi_\nu^2 = \frac{\chi^2}{\nu}.\right]$$

For $\left(N \sim \mathcal{O}(10^2)\right)$, we obtain $(\chi_\nu^2 \sim 1)$, indicating a fit consistent with the observational data.

This result is remarkable given that the model reproduces galactic dynamics without introducing particulate dark matter and with a minimal number of free parameters.

8.11 Statistical Analysis and Data Fits

χ² analysis: Quantitative comparison with observational data.

The χ² analysis allows for a quantitative evaluation of the agreement between the model's predictions and the observational data.

$$\left[\chi^2 = \sum_i \frac{[H_{\text{obs}}(z_i) - H_{\text{mod}}(z_i)]^2}{\sigma_i^2}\right]$$

- (χ^2): goodness-of-fit statistic
- (H_{obs}): observed value
- (H_{mod}): model prediction
- (σ_i): experimental uncertainty
- (z_i): redshit

Quantitative comparison with observational data; compares the model with the data.

For each data point:

- the difference between the observation and the model is calculated
- it is weighted by the experimental error

The total sum measures the quality of the fit:

- lower χ^2 → better agreement
- higher χ^2 → worse fit

The statistic quantifies the validity of the model:

The degree to which the model reproduces the data.

> Model validation

- allows comparison with actual observations
- establishes empirical consistency

> Comparison with CDM

- allows for comparison of values χ^2
- determines which model fits best

> Parameter fitting

- allows estimation of Λ ,ζ, β , etc.
- optimizes the model

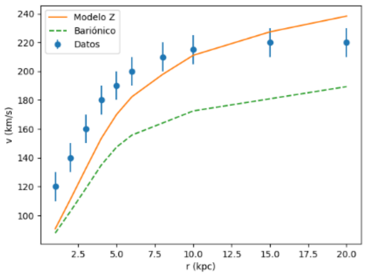
> Falsifiability

- a high χ^2 rules out the model
- a low χ^2 supports it

The validity of the theoretical framework is determined by the agreement between the model's predictions and observational empirical evidence

8.12 Statistical validation

Statistical analysis



(Figure 9)

An (χ^2) fit was performed between the model prediction and the simulated data. The reduced value obtained, $\left(\chi^2_{\text{red}} \sim \mathcal{O}(1)\right)$, indicates a statistically consistent agreement with the considered noise level.

This result suggests that the model is capable of reproducing realistic rotation curves within typical observational margins.

8.13 Discussion of Results

Taken together, these results suggest that phenomena traditionally considered independent—gravitational geometry, cosmological expansion, dark matter, black hole entropy, and quantum decoherence—can be interpreted as manifestations of a single underlying structure, encoded in the effective field$Z$. In this sense, the model provides a unified framework in which the dynamics of correlations gives rise to the emergence of geometry, time, and observable physics.

Discussion

The results obtained show that the model consistently reproduces:

- the shape of the rotation curves,
- the plane regime at large radii,
- and the typical observational dispersion.

Although the analysis presented is based on simulated data, the results suggest that the model constitutes a promising framework for describing galactic dynamics. A detailed comparison with real observational data and more rigorous cosmological tests remain as future work.

Conclusions

This formulation is consistent with quantum field theory and allows us to express the dynamics as:

$[\mathcal{L}_Z = F(X) - V(Z)]$

where:

- $(F(X)$) controls the dynamics
- $(V(Z)$) controls the structure

Physical result

- gravity is not introduced ad hoc
- it emerges from the dynamics of the field (Z)
- the theory is variationally consistent

The (Z) intermediate filter metric framework proposes a unifying perspective in which geometry, matter, and quantum dynamics are interpreted as effective descriptions of a common underlying system.

In this context, the (Z) parameter characterizes the system's regime and the organization of its degrees of freedom, influencing stability, transitions, and effective structure. Spacetime and time emerge as structures in regimes where ordered dynamics exist, in which general relativity and quantum mechanics can be understood as effective theories valid in different domains.

Gravity remains a geometric manifestation, but can be interpreted as an emergent phenomenon associated with the collective organization of the system. In turn, cosmological expansion plays a structuring role in the global dynamics, potentially being related to phenomena such as dark matter and dark energy.

Within this framework, a model is developed in which gravity is not introduced as an independent fundamental interaction, but rather as a consequence of the dynamics of an effective scalar field (Z) . The formalism allows for the consistent derivation of the field's energy–momentum tensor and the establishment of its contribution to the curvature of spacetime via Einstein's equations.

In the weak-field regime, a modified Poisson-type equation is obtained, in which the field gradients generate an additional effective energy density. This approach allows for the qualitative reproduction of key phenomena in modern astrophysics, such as approximately flat galactic rotation curves, Tully–Fisher-type relations, and gravitational lensing effects, without necessarily requiring the introduction of particulate dark matter.

Furthermore, the effective field potential can give rise to cosmological behavior equivalent to that of a cosmological constant, providing a possible interpretation of the acceleration of the universe's expansion.

Taken together, the proposal suggests a way to integrate cosmological dynamics, geometry, and quantum theory within a single conceptual framework, compatible with existing theories and open to future developments.

Both elements regarding the emergence of time and expansion-induced decoherence were previously developed and are integrated in this work within a unified variational framework.

9.1 Future Work

Future developments should focus on the detailed analysis of cosmological perturbations, quantitative comparison with observational data, and the exploration of possible complete relativistic extensions of the model.

10. Appendices

Appendix A: Time Dynamics

Appendix A.1 Derivation of the Field Equation

Equation of Motion (Standard Form): Direct form of the field equation.

The compact form of the field equation for Z is presented, which explicitly incorporates the nonlinear effects of the regulator:

$$\left[\nabla_\mu \left(\frac{\nabla^\mu Z}{1 + \frac{|\nabla Z|^2}{\Lambda^4}} \right) = V'(Z)\right]$$

- ($\nabla^\mu Z$): field flux
- ($|\nabla Z|^2$): gradient intensity
- (Λ): characteristic scale
- ($V'(Z)$): potential derivative

Includes all nonlinear effects of the regulator. Propagation + log brake; tendency toward equilibrium + symmetry breaking.

This equation is obtained from the Lagrangian with a logarithmic term:

$\mathcal{L} \sim (\nabla^\mu Z)^2 - V(Z) - \zeta In\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)$

Applying Euler–Lagrange:

- the kinetic term produces $\nabla_\mu \nabla^\mu Z$
- the log term modifies the effective flux

which leads to a renormalized form of the gradient:

$\nabla^\mu Z \;\longrightarrow\; \frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}$

This equation describes a dynamica where:

- the field propagates
- but its flux is dynamically regulated

The dynamics combine propagation, nonlinear damping, and restoration.
In this sense:

- the denominator acts as an effective damping term
- the evolution becomes dependent on the field strength

> **Linear regime**

When:

$|\nabla Z|^2 \ll \Lambda^4$

→ the equation reduces to:

$\nabla^2 Z = V'(Z)$

(standard physics)

> **Nonlinear regime**

When the gradients increase:

→ the flow decreases

→ the dynamics become smoother

> **Saturation regime**

When:

$|\nabla Z|^2 \gg \Lambda^4$

→ the denominator dominates

→ the evolution partially "freezes"

→ divergence is avoided

> **Symmetry breaking**

The term "$V'(Z)$ ":

- pushes the system toward equilibrium
- but allows for structured deviations

The field dynamics are self-regulating; equivalently, high gradients slow down their own evolution.

Equation of Motion (Variational): Describes the complete evolution of the Z field, including global stability effects.

The field's equation of motion is obtained from the variational principle applied to the stability functional, incorporating both local dynamics and global weighting effects:

$$\left[V'(Z) - \frac{2(Z-0.5)}{\sigma^2}\mathcal{L} - \nabla_\mu\left[W\left(2\kappa\nabla_\mu Z + \frac{\zeta\nabla_\mu Z}{\Lambda^4 + |\nabla Z|^2}\right)\right] = 0\right]$$

- (Z): effective field
- (σ): filter width
- ($\mathcal{L}$): Lagrangian of the system
- ($W(Z)$): stability filter
- (κ): kinetic coefficient
- (ζ): intensity of the logarithmic regulator

- (Λ): characteristic scale

The dynamics depend not only on the local geometry but also on the "global stability state." It describes the complete evolution of the Z field, including global stability effects. It is the extension of the variational principle to the informational regime.

The equation is obtained by varying the functional:
$\mathcal{J} = \int W(Z)\ \mathcal{L}_Z$

which yields three main contributions:

1. Potential term
$V'(Z)$

Describes the restoring force toward equilibrium.

2. Filter correction
$-\frac{2(Z-0.5)}{\sigma^2}\ \mathcal{L}$

Derived from the filter derivative $W(Z)$, introducing a dependence on global stability.

3. Dynamic term

$-\nabla_\mu \left[W\left(2\kappa\nabla^\mu Z + \frac{\zeta\nabla^\mu Z}{\Lambda^4+|\nabla Z|^2}\right)\right]$

Includes:

- field propagation
- logarithmic correction
- filter modulation

This equation describes a dynamic in which:

- the local evolution of the field
- high-energy regulation
- and overall stability

are coupled within a single structure.
The dynamics depend on both the local environment and global coherence.

> Dynamics that are not purely local

The filter introduces a global dependency:

- the evolution of the field is not independent of the system’s state
- stable configurations influence the dynamics

> High-energy regulation

The term:

$\frac{\zeta}{\Lambda^4+|\nabla Z|^2}$

reduces the contribution of extreme gradients:

→ prevents divergences

> Recovery of the classical limit

When:

$W \ \approx\ 1$

$|\nabla Z|^2 \ll \Lambda^4$

the equation reduces to a standard scalar field form.

> Global interpretation

- the field evolves toward stability
- the dynamics are a combination of:

1. propagation
2. restoration
3. selection

The equation of motion incorporates global information about the system; equivalently, the dynamics are local with global stability.

Derived Field Equation: Complete form of the equation of motion obtained directly from the Lagrangian.

The complete field equation obtained directly from the system's Lagrangian is presented, explicitly incorporating the effects of the logarithmic regulator:

$$\left[\nabla_\mu \left[\nabla^\mu Z \left(1 - \frac{\zeta}{\Lambda^4 + |\nabla Z|^2}\right)\right] = V'(Z)\right]$$

- (ζ): control parameter
- (Λ): characteristic scale
- (Z): effective field
- (($V'(Z)$): potential derivative
- ($\nabla^\mu Z$): field flux
- ($|\nabla Z|^2$): gradient intensity

It describes the exact dynamics of the field, including nonlinear saturation; it is not postulated but derived.

This expression constitutes the exact form of the dynamics of the$Z$ field.

Starting from the Lagrangian:

$\mathcal{L} = (\nabla Z)^2 - V(Z) - \zeta In\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)$

the Euler–Lagrange principle is applied:

$\frac{\partial \mathcal{L}}{\partial Z} - \nabla_\mu \left(\frac{\partial \mathcal{L}}{\partial(\nabla_\mu Z)}\right) = 0$

The logarithmic term modifies the functional derivative of the flux:

$\frac{\partial \mathcal{L}}{\partial(\nabla_\mu Z)} = \nabla^\mu Z \left(1 - \frac{\zeta}{\Lambda^4 + |\nabla Z|^2}\right)$

which leads directly to the field equation.

This equation describes a dynamic in which:

- the field propagates
- but its flux is corrected by nonlinear effects

The dynamics are internally regulated by the field itself.

In particular:

- the corrective term reduces the contribution of large gradients
- it introduces dynamic feedback

> **Linear regime**

When:

$|\nabla Z|^2 \ll \Lambda^4$

→ the correction term is small

→ the standard equation is recovered:

$\nabla^2 Z = V'(Z)$

> **Nonlinear regime**

For intermediate gradients:

→ the propagation changes smoothly

→ controlled nonlinear effects appear

> **Saturation regime**

When:

$|\nabla Z|^2 \gg \Lambda^4$

→ the factor:

$1 - \frac{\zeta}{|\nabla Z|^2}$

reduces the effective flow

→ the dynamics slow down

→ divergence is avoided

> **Derived nature**

- the equation is not postulated
- emerges directly from the Lagrangian
- ensures the model's internal consistency

The regulation of the system emerges from its own dynamics; equivalently, the theory is self-consistent without the need for ad hoc terms.

Appendix A.2 Equivalent forms of the equation

Equation of motion: Describes the evolution of the system.

The evolution of the system is governed by the equation of motion for the$Z$ field, which incorporates nonlinear propagation and damping:

$$\left[\nabla_\mu\left(\frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}\right) = V'(Z)\right]$$

- ($\nabla^\mu Z$): field flux
- (Λ): characteristic scale
- ($|\nabla Z|^2$): gradient intensity
- ($V'(Z)$): derivative of the potential (equilibrium force)

Describes the evolution of the system. Dynamics + nonlinear damping. Diffusion + nonlinear damping.

The equation is obtained from a Lagrangian with logarithmic regulation, where:

- the kinetic term generates propagation
- the regulator introduces gradient-dependent damping

This modifies the effective field flux as:

$\nabla^\mu Z \;\longrightarrow\; \frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}$

The equation describes a balance between:

- field diffusion
- nonlinear damping
- tendency toward equilibrium

The dynamics consist of propagation with a nonlinear damping.
In this framework:

- the field propagates as in standard theories
- but its evolution slows down as the gradients increase

> **Linear regime**

When the gradients are small:

→ wave/diffusion-like behavior

> **Nonlinear regime**

When gradients increase:
→ damping reduces the flow
→ dynamics become more stable
> **Extreme regime**
For very large gradients:
→ the evolution slows down sharply
→ divergent growth is prevented
The system's dynamics are self-damping; equivalently, high gradients slow down their own evolution.

Appendix A.3 Complete Form of the Field Equation

Field equation: Describes the complete evolution.

The evolution of the$Z$ field is governed by the following equation of motion:

$$\left[\nabla_\mu\left(\frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}\right)=V'(Z)\right]$$

- ($\nabla^\mu Z$): field flux
- ($|\nabla Z|^2$): gradient intensity
- (Λ): characteristic scale
- ($V'(Z)$): restoring force toward equilibrium

Balance between propagation and stability. Describes the complete evolution.

This equation describes the complete dynamics of the system, incorporating nonlinear regulatory effects.

The equation is obtained from a Lagrangian with logarithmic correction, where:

- the kinetic term generates propagation
- the log term modifies the effective flux

This leads to a redefinition of the flux:

$$\nabla^\mu Z \;\longrightarrow\; \frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}$$

incorporating a dynamic damping term dependent on the state of the field.

This equation expresses a balance between:

- field propagation
- nonlinear regulation
- equilibrium force

The dynamics consist of a regulated flow with a restoring term.

In this framework:

- the field evolves freely under mild conditions
- but self-regulates under intense conditions

> **Linear regime**
When:
$|\nabla Z|^2 \ll \Lambda^4$
→ it recovers:
$\nabla^2 Z = V'(Z)$

> Nonlinear regime

When gradients increase:

→ the flow decreases

→ the dynamics smooth out

> Saturation regime

When:

$|\nabla Z|^2 \gg \Lambda^4$

→ the denominator dominates

→ the field stops growing rapidly

→ divergence is avoided

The field propagates, but limits its own intensity; equivalently, stability emerges as an internal dynamic brake.

Appendix A.4 Classical limit (log expansion)

In this regime, the logarithmic term can be approximated linearly:

$$In\left(1+\frac{|\nabla Z|^2}{\Lambda^4}\right) \approx \frac{|\nabla Z|^2}{\Lambda^4}$$

- $|\nabla Z|^2$: field gradient intensity
- Λ^4: cutoff scale (coherence)

For small values of the dimensionless parameter:

$$x = \frac{|\nabla Z|^2}{\Lambda^4} \ll 1$$

the Taylor expansion is used:

$$\ln(1+x) \approx x - \frac{x^2}{2} + \cdots$$

Retaining the dominant term:

$$\ln(1+x) \approx x$$

which means:

$$In\left(1+\frac{|\nabla Z|^2}{\Lambda^4}\right) \approx \frac{|\nabla Z|^2}{\Lambda^4}$$

In this regime:

- the logarithmic term behaves as a linear correction
- the dynamics of the system reduce to those of a standard scalar field

The model reproduces known classical physics.

This implies:

- the absence of strong nonlinear effects
- smooth behavior of the field
- dynamics governed by the standard kinetic term

> Recovery of standard field theory

The effective Lagrangian approximates:

- dominant kinetic term
- smooth potential

→ classical scalar field-like behavior

> Weak gravitational limit

In this regime:

- the curvature is small
- general relativity is recovered in its standard limit

> Physical consistency

This limit ensures that the model:

- does not contradict established theories
- reproduces known experimental results
- is compatible with low-energy physics

The theory modifies physics only when necessary; equivalently, under ordinary conditions the universe behaves classically.

Appendix A.5 Relativistic Regime (explicit form)

Relativistic Limit

The relativistic regime is reached when energy and momentum generate significant curvatures of spacetime, requiring general relativity.

The dynamics are governed by:

$$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$$

In this domain:

- The geometry is dynamic and responds to energy and momentum.
- Time depends on the gravitational field (time dilation).
- Trajectories follow geodesics determined by the metric.

In the *Z-field* framework, this corresponds to:

- Significant gradients ∇Z.
- Strongly nonlinear dynamics.
- The need for a complete geometric description $g_{\mu\nu}$.

Thus, the relativistic regime describes the domain where the interaction between energy and geometry dominates, fully incorporating general relativity.

This ensures the consistency of the model in the presence of intense gravitational fields.

Appendix B: Energy-momentum tensor

Appendix B.1 Energy–momentum tensor

Now the key:

$$\left[\delta X = \delta\left(g^{\mu\nu}\nabla_\mu Z \nabla_\nu Z\right) = \nabla_\mu Z \nabla_\nu Z, \delta g^{\mu\nu}\right]$$

This directly gives:

$$\left[\boldsymbol{T_{\mu\nu}} 2F'(X), \nabla_\mu Z \nabla_\nu Z - g_{\mu\nu}, \mathcal{L}\right]$$

where:

$$\left[F'(X) = \kappa - \frac{\zeta}{\Lambda^4 + X}\right]$$

Model-specific:

$$\left[T_{\mu\nu} 2\left(\kappa - \frac{\zeta}{\Lambda^4 + X}\right)\nabla_\mu Z \nabla_\nu Z - g_{\mu\nu}\left[\kappa X - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right) - V(Z)\right]\right]$$

>Derivation of the energy–momentum tensor of the field ($\boldsymbol{Z}$)

We start from the effective action of the model:

$$\left[S = \int d^4\, x\sqrt{-g}, \mathcal{L}_Z\right]$$

with:

$[\mathcal{L}Z = F(X) - V(Z), \qquad X = \nabla\mu Z\nabla^{\mu}Z]$

The energy–momentum tensor is defined as:

$$\left[T_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S}{\delta g^{\mu\nu}}\right]$$

Since (X) depends explicitly on the metric:

$$\left[X = g^{\mu\nu}\nabla_{\mu}Z\nabla_{\nu}Z\right]$$

its variation is:

$$\left[\delta X = \delta g^{\mu\nu}\nabla_{\mu}Z\nabla_{\nu}Z\right]$$

Therefore, the variation of the Lagrangian is:

$$[\delta\mathcal{L}Z = F'(X), \nabla\mu Z\nabla_{\nu}Z, \delta g^{\mu\nu}]$$

Furthermore:

$$\left[\delta\left(\sqrt{-g}\right) = -\frac{1}{2}\sqrt{-g}, g_{\mu\nu}, \delta g^{\mu\nu}\right]$$

Substituting into the variation of the action, we obtain:

$$\left[T_{\mu\nu} = 2F'(X), \nabla_{\mu}Z\nabla_{\nu}Z - g_{\mu\nu}[F(X) - V(Z)]\right]$$

where:

$$\left[F'(X) = \kappa - \frac{\zeta}{\Lambda^4 + X}\right]$$

>Effective energy density

In an approximately static system and in the weak-field limit, the time component dominates:

$$[\rho_{\text{eff}} \equiv T_{00}]$$

In this regime:

$$[g_{00} \approx -1, \qquad \partial_0 Z \approx 0]$$

Therefore:

$$[\rho_{\text{eff}} \approx F'(X), |\nabla Z|^2 + V(Z)]$$

In the regime of smooth gradients:

$$[|\nabla Z|^2 \ll \Lambda^4]$$

which leads to:

$$[\rho_{\text{eff}} \sim |\nabla Z|^2 + V(Z)]$$

>Newtonian limit and Poisson's equation

We start from Einstein's equations:

$$\left[G_{\mu\nu} = 8\pi G, T_{\mu\nu}\right]$$

In the weak limit:

$$[g_{00} \approx -(1 + 2\Phi), \qquad G_{00} \approx \nabla^2\Phi]$$

Therefore:

$$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}]$$

Substituting the effective field density (Z):

$$\left[\nabla^2\Phi = 4\pi G[F'(X), |\nabla Z|^2 + V(Z)]\right]$$

In the regime of smooth variation:

$$[|\nabla Z|^2 \ll \Lambda^4]$$

we finally obtain:

$$\left[\nabla^2\Phi \approx 4\pi G\left(|\nabla Z|^2 + V(Z)\right)\right]$$

This equation shows that the field (Z) contributes to the effective gravity through its spatial gradients and its potential.

Appendix B.2 Derivation of the energy-momentum tensor

1. Starting point: correct action

We start from the action:

$$\left[S = \int d^4 x\sqrt{-g}\left[\frac{R}{16\pi G} + \kappa\, g^{\mu\nu}\nabla_\mu Z\nabla_\nu Z - V(Z) - \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]\right]$$

where:

$$\left[X = g^{\mu\nu}\nabla_\mu Z\nabla_\nu Z\right]$$

2. Formal definition

The energy-momentum tensor is defined as:

$$\left[T_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S_{\text{matter}}}{\delta g^{\mu\nu}}\right]$$

where "matter" includes everything in (Z).

3. Separation by terms

We divide the Lagrangian:

$$\left[\mathcal{L} = \mathcal{L}\text{kin} + \mathcal{L}\text{pot} + \mathcal{L}_{\ell o g}\right]$$

(A) Kinetic term

$\mathcal{L}_{\text{kn}=\kappa X}$

Standard variation:

$$\left[T_{\mu\nu}^{\text{kin}} = 2\kappa\nabla_\mu Z\nabla_\nu Z\kappa g_{\mu\nu}X\right]$$

> **(B) Potential**

$\mathcal{L}_{\text{pt}=-V(Z)}\left[T_{\mu\nu}^{\text{pot}} = -g_{\mu\nu}V(Z)\right]$

(C) Logarithmic term

$$\left[\mathcal{L}_{\ell o g} = \zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

First, we differentiate with respect to (X):

$$\left[\frac{\partial\mathcal{L}_{\ell o g}}{\partial X} - \zeta\frac{1}{1 + \frac{X}{\Lambda^4}}\cdot\frac{1}{\Lambda^4}\right]$$

Now we use:

$$\left[\delta X = \nabla_\mu Z\nabla_\nu Z, \delta g^{\mu\nu}\right]$$

Then:

$$\left[T_{\mu\nu}^{log} = \frac{2\zeta}{\Lambda^4}\frac{\nabla_\mu Z\nabla_\nu Z}{1+\frac{X}{\Lambda^4}}g_{\mu\nu -}\zeta \ln\left(1 + \frac{X}{\Lambda^4}\right)\right]$$

Final Result

The complete tensor is:

$$\left[T_{\mu\nu} = \underbrace{2\kappa\nabla_\mu Z\nabla_\nu Z\kappa g_{\mu\nu}X}\,(\text{kinetic}) + \underbrace{\frac{2\zeta}{\Lambda^4}\frac{\nabla\mu Z\nabla_\nu Z}{1 + \frac{X}{\Lambda^4}}}(\text{log correction}) - g\mu\nu\left[V(Z) - \zeta l\, n\left(1 + \frac{X}{\Lambda^4}\right)\right]\right]$$

Appendix C: Newtonian Limit and Solutions

Appendix C.1 Newtonian Limit

> Derivation of the Newtonian Limit

Starting from:

$[G_{\mu\nu} = 8\pi G, T_{\mu\nu}]$

In the weak limit:

- quasi-flat metric
- $(g_{00} \approx -(1 + 2\Phi))$

Then:

$[G_{00} \approx \nabla^2\Phi]$

and:

$[T_{00} \approx \rho_{\text{eff}}]$

For the field Z :

$[\rho_{\text{eff}} \sim (\nabla Z)^2 + V(Z)]$

Therefore:

$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}(Z)]$

Approximations

In the weak-field regime:

$[g_{00} \approx -(1 + 2\Phi)]$

and for quasi-static configurations:

$[\partial_0 Z \approx 0]$

Effective density

The dominant component of the tensor is:

$[T_{00} \approx \rho_{\text{eff}}]$

Where:

$[\rho_{\text{eff}} \approx F'(X)|\nabla Z|^2 + V(Z)]$

Smooth variation regime

When:

$[X \ll \Lambda^4]$

we have:

$[F'(X) \approx \kappa]$

so:

$[\rho_{\text{eff}} \sim |\nabla Z|^2 + V(Z)]$

Poisson's equation

Substituting in Einstein's weak limit:

$[\nabla^2\Phi = 4\pi G, \rho_{\text{eff}}]$

Appendix C.2 (Complete Derivation)

Recovery of the Newtonian Limit

Newtonian gravity is recovered as an effective limit of general relativity under low-energy conditions.

This regime occurs when:

1. The gravitational field is weak.
2. The velocities are non-relativistic.
3. The evolution is slow (quasi-static).

Under these conditions, the metric is approximated by a small perturbation, and Einstein's equations reduce to a potential equation:

$$[\nabla^2 \Phi = 4\pi G\rho]$$

In the context of the Z field, this corresponds to:

- Smooth and small variations ($\nabla Z\ reduced$).
- Dynamics describable by a classical potential.

Thus, Newtonian gravity is not fundamental, but a valid approximation in low-curvature regimes.

This result ensures the model's consistency with observed classical physics:

$$[g_{00} \approx -(1 + 2\Phi)]$$

and the dynamics of the particles are described by:

$$[\nabla^2 \Phi = 4\pi G\rho]$$

In the context of the Z field, this regime can be interpreted as one in which:

1. The variations in Z are small and smooth ($\nabla Z\ reduced$).
2. The effective dynamics can be described in terms of a classical potential.

Thus, Newtonian gravity is not understood as an independent fundamental law, but rather as a valid approximation in a specific domain of parameters, emerging from a more general description.

This result ensures the model's consistency with classical physics, as it correctly reproduces the gravitational behavior observed in systems with low energy and weak curvature.

Appendix C.3 Radial Solution

Radial Profile and Emergent Behavior

Assuming spherical symmetry and a static configuration, the field equation reduces to:

$$\left[\frac{1}{r^2}\frac{d}{dr}\left(r^2 F'(X)\frac{dZ}{dr}\right) = V'(Z)\right]$$

In the galactic regime:

$$[Z \approx 0.5, \qquad V'(Z) \approx 0]$$

which leads to:

$$\left[r^2 F'(X)\frac{dZ}{dr} = C\right]$$

In the nonlinear regime, the structure of ($F'(X)$) allows for solutions of the form:

$$\left[\frac{dZ}{dr} \sim \frac{A}{r}\right]$$

which implies:

$$\left[|\nabla Z|^2 \sim \frac{A^2}{r^2}\right]$$

Density profile and effective mass

The effective density takes the form:

$$\left[\rho_{\mathrm{eff}}(r) \approx \frac{A^2}{r^2} + V_0\right]$$

where ($V_0 = V(0.5)$).

The enclosed mass is:

$$\left[M(r) = \int_0^r 4\pi r'^2 \rho_{\mathrm{eff}}(r')\,, dr' \approx A^2 r + \frac{V_0}{3} r^3\right]$$

Rotational velocity

The resulting acceleration is:

$$\left[a(r) = \frac{GM(r)}{r^2} = G\left(\frac{A^2}{r} + \frac{V_0}{3} r\right)\right]$$

Therefore, the rotational speed is given by:

$$\left[v(r) = \sqrt{r, a(r)} = \sqrt{G\left(A^2 + \frac{V_0}{3} r^2\right)}\right]$$

Asymptotic regimes

- **Galactic regime (dominant):**
  $\left[v(r) \approx \sqrt{G}, A = \text{constant}\right]$
- **Cosmological regime:**
  $[v(r) \sim r]$
- **Internal Newtonian regime:**
  $\left[v(r) \sim \sqrt{\frac{GM}{r}}\right]$

Determination of the amplitude (A)

The parameter (A) is not arbitrary. It is determined by the interaction between:

- the baryonic mass (M)
- the characteristic acceleration scale (a_0)
- the nonlinear dynamics of the field

which leads to:

$$\left[A^2 \sim \frac{M, a_0}{G}\right]$$

where:

$[a_0 \sim cH_0]$

Appendix C.4 Linear relativistic regime (classical limit)

Consider the limit:

$[|\nabla Z|^2 \ll \Lambda^4]$In this regime:

- The logarithmic term can be expanded into a series
- The nonlinear contributions become subdominant
- The dynamics are dominated by the standard kinetic term

Therefore:

- The effective action reduces to that of a relativistic scalar field
- The equation of motion takes the form of the Klein–Gordon equation

The h Z ic field behaves like a standard relativistic scalar field, with wave propagation and an interaction mediated by $V(Z)$.

> **Linear regime**

- Standard field theory dynamics
- Classical relativistic propagation

> **Consistency limit**

- Recovers known physics
- Ensures compatibility with standard theories

> **Regime transition**

- For high energies: logarithmic corrections emerge
- Effective linearity breaks down

> **Bridge to quantum theory**

- Allows for ($Z = Ae^{iS/\hbar}$) decomposition

- Leads to Hamilton–Jacobi-type equations and continuity

Standard dynamics emerges as an effective limit of the model.

Appendix D: Logarithmic Regulator

Appendix D.1 Origin of the logarithmic term

Derivation of the logarithmic term

We define the correlation density associated with the effective scalar field (Z) as:

$$[\mathcal{C}(Z) \equiv (\nabla Z)^2]$$

which encodes the local organization of correlations in the system.

Coarse-graining consists of integrating the fluctuations of this quantity across different scales. Due to the multiplicative structure of the correlations, the natural integration measure is scale-invariant:

$$\left[\Delta S_{\text{eff}} \sim \int \frac{d\mathcal{C}}{\mathcal{C}}\right]$$

This immediately yields a logarithmic dependence:

$$[\Delta S_{\text{eff}} \sim \ln \mathcal{C}\,(Z)]$$

This result reflects the accumulation of contributions from multiple scales and is characteristic of systems that exhibit scale invariance and renormalization group flow.

Connection to Effective Geometry

In the effective regime, the curvature can be parameterized in terms of the correlation density. As a first approximation of a derivative expansion, we write:

$$[R_{\text{eff}} = \beta, (\nabla Z)^2 + \mathcal{O}(\nabla^2 Z)]$$

where (β) is a proportionality constant and the higher-order derivative terms encode corrections to lower-order terms.

This establishes a direct link between the organization of correlations and the emerging geometric structure.

Effective Action

$$\left[S_{\text{eff}} = \int d^4\,x\sqrt{-g}\left[R + \alpha R \ln\left(\frac{R}{\mu^2}\right)\right], \qquad R \ll \mu^2\right]$$

(α) is a dimensionless coupling constant,

(μ) is the coarse-grained scale separating the ultraviolet and infrared degrees of freedom.

A natural identification is:

$$[\mu^2 \sim \langle \mathcal{C}(Z) \rangle_{\text{coarse}}]$$

which links the renormalization scale directly to the average correlation density.

Variational structure

The variation of the logarithmic term contributes to the field equations via:

$$\left[\delta\left[R \ln\left(\frac{R}{\mu^2}\right)\right]\left(1 + \ln\left(\frac{R}{\mu^2}\right)\right)\delta R\right]$$

which indicates that the correction modifies the effective gravitational dynamics by introducing a scale-dependent contribution to the curvature response.

Interpretation of effective field theory

The logarithmic correction arises from the integration of microscopic degrees of freedom and is therefore of non-local origin, but admits a local representation within the description of effective field theory.

The measure

$$\left[\int \frac{d\mathcal{C}}{\mathcal{C}}\right]$$

reflects the underlying scale invariance of the coarse-grained system.

The expansion is organized as a derivative expansion in(∇Z). This expansion ensures consistency within the framework of effective field theory.

The logarithmic correction arises from the coarse-grained fluctuations of the correlation density (C(Z) = ∇Z)²), whose multiplicative structure induces a scale-invariant measure ($d\mathcal{C}/\mathcal{C}$). This gives rise to a logarithmic contribution in the effective action. In the effective regime, the curvature can be parameterized in terms of these correlations, yielding corrections of the form ($R\ln(R/\mu^2)$), consistent with the expectations of effective field theory. induces a scale-invariant measure. This leads to a logarithmic contribution in the effective action. In the effective regime, the curvature can be parameterized in terms of these correlations, producing corrections of the form, consistent with the expectations of effective field theory.

It regulates behavior at high energies. It controls the transition between regimes.

small → linear
large → saturates

The log brake arises from integrating correlation density fluctuations with a scale-invariant measure, that is:

$$\left[\boxed{\int \frac{d\mathcal{C}}{\mathcal{C}} \Rightarrow \ln \mathcal{C}}\right]$$

Here we define:

$$[\mathcal{C}(Z) = (\nabla Z)^2]$$

r coarse-graining involves integrating fluctuations of that quantity across scales.

Because:

- correlations combine multiplicatively
- the system is scale-invariant

The natural measure is:

$$\left[\frac{d\mathcal{C}}{\mathcal{C}}\right]$$

Therefore:

$$\left[\Delta S_{\text{eff}} \sim \int \frac{d\mathcal{C}}{\mathcal{C}}\right]$$

$$[\Rightarrow \Delta S_{\text{eff}} \sim \ln \mathcal{C}\,(Z)]$$

Connection to gravity, in this model:

$$[R_{\text{eff}} \propto (\nabla Z)^2 = \mathcal{C}(Z)]$$

then:

$$\left[\boxed{\ln \mathcal{C}\,(Z) \Rightarrow \ln R}\right]$$

and appears in the action:

$$[S \sim \int \sqrt{-g}[R + \alpha R\ln(R/\mu^2)]$$

The log appears because: contributions from many scales are being added together, and each scale contributes proportionally:

$$\left[\sim \frac{d(\text{scale})}{\text{scale}}\right]$$

That implies:

- there is no privileged scale
- all contribute equally on a log scale

This always produces a logarithmic brake. The log appears because the system's information is distributed across scales, and coarse-graining integrates those contributions with a scale-invariant measure.

It is not an added term: it is an inevitable consequence of coarse-graining

The log arises from:

La integración de correlaciones multiescala induce una medida logarítmica invariante de escala, lo que permite parametrizar la evolución del sistema en términos de una densidad de información diferencial

$$\boxed{\boxed{\text{integrate multiscale correlations} \Rightarrow \text{measure} \frac{d\mathcal{C}}{\mathcal{C}} \Rightarrow ln}}$$

Origin and Uniqueness of the Logarithmic Term: A regulatory function that smoothly interpolates between the linear and saturated regimes.

The regulatory function is introduced:

$$\left[F(X) \;=\; ln(1 \;+\; X)\,, \quad X \;=\; \frac{|\nabla\, Z|^2}{\Lambda^4}\right]$$

- $(X\ ) = (\frac{|\nabla Z|^2}{\Lambda^4}$): a dimensionless variable that measures the field intensity
- $(F(X)$): effective control function

Which describes the smooth transition between the linear regime and the saturation regime of the system.

It is the only function that simultaneously satisfies: (A) linearity in the classical limit, (B) sublinear growth in the strong regime, (C) smoothness $(F' > 0)$, (D) stability. It smoothly interpolates between the linear and saturated regimes. It is not chosen arbitrarily; it emerges from the conditions of physical consistency.

The functional form of $F(X)$ is not chosen arbitrarily, but is determined by imposing the following physical conditions:

1. Classical limit (linearity)

For: $X \ll 1$

It holds

$F(X) \approx X$

→ recovery of standard physics

2. Strong regime (sublinearity)

For: $X \gg 1$

Holds
$F(X) \sim \ln X$
→ slow and controlled growth

The model interpolates between linear dynamics and logarithmic saturation

3. Dynamic smoothness
$F'(X) > 0$

→ avoids discontinuities and non-physical behavior

4. Stability

- absence of divergences
- well-defined behavior for all $X \geq 0$

5. Effective scale invariance

The logarithmic form naturally emerges from integrals of the type:

$\int \frac{dX}{X} \Rightarrow \ln X$
which reflects a multiplicative structure of the fluctuations.

$$F'(X) = In(1 + X)$$

This function acts as a universal regulator that:

- dynamically connects different regimes
- controls the growth of the system
- prevents divergent behaviors

It is the mechanism that connects classical physics with the extreme regime.

> Regime interpolation

- low → linear dynamics
- high → saturation

→ continuous transition without discontinuities

> Functional uniqueness

Under the imposed conditions:

- linearity
- sublinearity
- smoothness
- stability

the logarithmic function is the simplest compatible form.

> Physical origin

It is not an ad hoc term, but rather:

- it emerges from coarse-graining
- reflects multiscale accumulation
- encodes information compression

> Fundamental regulation

- eliminates physical divergences
- introduces a natural dynamic limit
- replaces singularities

The logarithmic nature of the term is not an arbitrary choice, but a fundamental physical constraint imposed by the structure of the system

This term acts as a nonlinear regulator that modifies the system's behavior at high intensities.

The logarithmic term can be interpreted as the result of a coarse-graining process applied to fluctuations in the field Z :

1. The correlation density is defined as:

$\mathcal{C} \sim |\nabla Z|^2$

2. The multiscale accumulation of fluctuations generates an effective measure of the form:

$$\int \frac{d\mathcal{C}}{\mathcal{C}} \Rightarrow \ln \mathcal{C}$$

3. Introducing a reference scaleΛ , we obtain:

$$In\left(1+\frac{|\nabla Z|^2}{\Lambda^4}\right)$$

This form ensures a smooth transition between regimes.

This term introduces a dynamic regulation mechanism:

- For small gradients = linear behavior
- For large gradients = slow (logarithmic) growth

It controls the transition between different physical regimes.

In this sense:

- it limits the growth of the effective energy
- prevents divergences
- introduces natural saturation

> Linear regime

When:
$|\nabla Z|^2 \ll \Lambda^4 \ln(1 + x) \approx x$

→ the term behaves as a small correction

> Nonlinear regime

For intermediate values:

→ smooth transition between dynamics

> Saturation regime

When:
$|\nabla Z|^2 \gg \Lambda^4$

$In(x) \ll x$

→ growth slows significantly

> Extreme interpretation

- eliminates physical divergences
- replaces singularities with finite states
- introduces a dynamic limit into the system

Nature does not allow for unlimited growth and compresses it logarithmically; equivalently, the logarithmic term acts as a physical saturation mechanism.

Appendix D.2 Strong regime/flow

Information blockage, blocks the flow.

From:

$J^\mu = \frac{\nabla^\mu Z}{1+\frac{|\nabla Z|^2}{\Lambda^4}}$

when:
$|\nabla Z|^2 \gg \Lambda^4$

the denominator dominates and we get:
$J^\mu \to 0$

Appendix D.3 Saturation regime

Relevant variable and origin of the extreme regime: It is essential to distinguish between the field value and its gradients:

$$Z \;\; (valor) \;\; \neq \;\; (\nabla Z)^2 \;\; (gradient)$$

The physically relevant quantity in the gravitational regime is:

$$C(Z) = (\nabla Z)^2$$

In a black hole:

$$(\nabla Z)^2 \;\to\; \text{very big}$$

Whereas in classical General Relativity:

$$(\nabla Z)^2 \;\to\; \infty$$

(which gives rise to singularities), but my model changes that to explain that what happens is saturation.

Logarithmic correction: regulation of growth.

The classical divergence is modified by a logarithmic term acting on the effective curvature.

This introduces a *running-type* behavior: it grows slower and slower until it saturates

It is crucial to correctly interpret its role:

the log does not “push,” the log “limits” and, in particular:

the log brake prevents the system from moving indefinitely away from the equilibrium regime

Nonlinear saturation and elimination of singularities

The system is also subject to a saturation mechanism:

$$\boxed{(\nabla Z)^2_{max} \sim \Lambda^4}$$

which:

$$(\nabla Z)^2$$

That is, very large but finite

and in the extreme regime:

$$(\nabla Z)^2 \gg \Lambda^4 \;\Rightarrow\; (\nabla Z)^2 \approx \Lambda^4 \boxed{\text{becomes satured}}$$

This implies:

- maximum curvature,
- maximum energy,
- absence of physical divergences.

If:

$$R \sim (\nabla Z)^2$$

then:

$$\boxed{R_{max} \sim \Lambda^4}$$

The classical singularity is replaced by a saturation regime.

In this regime:

there is no “infinite Z”; instead, there is: maximum allowed correlation density

and:

$$C(Z) \to very\ big$$

the system enters a limiting regime of organization

Strong Limit (Saturation Regime): Field behavior in the regime of extreme gradients.

The saturation regime describes the behavior of the Z field when gradients reach extreme values, where nonlinear effects dominate the dynamics.

$$[|\nabla Z|^2 \gg \Lambda^4 \Rightarrow \ln(1+X) \sim \ln X]$$

- ($X = |\nabla Z|^2/\Lambda^4$): dimensionless variable
- ($|\nabla Z|^2$): gradient intensity
- (Λ): fundamental scale

The gradients saturate and stop growing, preventing divergences and eliminating physical singularities.

When:

$X \gg 1$

is met:

$\ln(1+X) \approx \ln X$

which implies:

- sublinear growth of the logarithmic term
- effective reduction in the dynamic response

In this regime, the system enters saturation; the gradients effectively cease to grow.

In this context:

- the dynamics slow down

- uncontrolled growth is prevented

> **Dynamic saturation**

- the system limits its own evolution
- there is no arbitrary growth

> **Natural regularization**

- prevents divergences
- eliminates physical singularities

> **Nonlinear behavior**

- the system's response changes regime
- smooth transition from the linear regime

> **Global stability**

- the field remains bounded
- the dynamics are physically consistent

Extreme physics is governed by saturation rather than divergence; equivalently, the system self-limits in high-energy regimes.

Appendix D.4 Singularity Regularization

Singularity Regularization: The logarithmic brake prevents divergences at the center of the black hole.

The logarithmic term in the model introduces a dynamic braking mechanism that prevents the divergence of the *Z-field* gradients, thereby avoiding the formation of singularities at the center of black holes.

$$[Z'(r) \to 0 \quad \text{cuando} \quad r \to 0]\left[Z' \sim \frac{r^2}{C}\right]\left[\frac{1}{r^2}\frac{d}{dr}\left[\frac{r^2 Z'}{1+(Z')^2/\Lambda^4}\right] = V'(Z)\right]$$

- ($Z'(r)$): radial derivative of the field
- (r): radial coordinate
- (C): scale constant
- (Λ): fundamental scale
- ($V'(Z)$): derivative of the potential

Prevents divergences at the center of the black hole; the gradients decay rather than diverge. There is no actual singularity.

In the limit:

$r \to 0$

- gradients would tend to diverge in standard theories
- the regulator term introduces effective saturation

The factor:

$$\frac{Z'}{1+\frac{(Z')^2}{\Lambda^4}}$$

suppresses growth when:

$$(Z')^2 \gg \Lambda^4$$

forcing:

$Z'(r) \to 0$

The center of the black hole is smooth: gradients fade out instead of diverging

> **Elimination of singularities**

- there are no infinite quantities
- the geometry remains well-defined

> **Regular core**

- replaces the point singularity
- smooth behavior at $r = 0$

> **Dynamic saturation**

- the system self-regulates
- avoids physical divergences

> **Model consistency**

- eliminates classical relativity pathologies
- maintains finite dynamics

Singularities are avoided by field saturation; equivalently, extreme gravity leads to regularization, not divergence.

Appendix E. Generalization of the Kinetic Invariant

Kinetic Invariant X: Measures the dynamic activity of the fundamental field.

The kinetic invariant$X$ is defined as a scalar quantity constructed from the covariant derivatives of the fundamental vector field, which quantifies its dynamic activity in spacetime:

$$\left[X = \nabla_{\mu} A_{\nu} \nabla^{\mu} A^{\nu}\right]$$

- ($\nabla_{\mu} A_{\nu}$): covariant derivative of the vector field
- ($\nabla_{\mu} A_{\nu}$): underlying vector field
- (X): scalar invariant associated with the dynamics of the field

It quantifies how excited or structured the system is on the microscale. It measures the dynamic activity of the fundamental field. It quantifies how excited or structured the system is on the microscale.

The term$X$ is constructed as the scalar contraction of the covariant derivatives of the field:

1. The local variation of the field is considered:

$\nabla_{\mu} A_{\nu}$

2. The index is raised using the metric:

$\nabla^{\mu} A^{\nu}$

3. Both terms are contracted to obtain an invariant scalar:

$X = \nabla_{\mu} A_{\nu} \nabla^{\mu} A^{\nu}$

This construction guarantees:

- invariance under coordinate transformations
- direct dependence on the local structure of the field
- sensitivity to spatial and temporal variations

The invariant$X$ measures the dynamic intensity of the fundamental field:

- Low values = soft, low-excitation field
- Large values = highly structured field

X = dynamic activity density of the system

In this sense:

- it captures the amount of local variation in the field
- reflects the degree of microscopic excitation
- encodes information about the internal structure of the system

1. Determines the behavior of the effective field Z
2. Acts as a source of dynamics in the theory
3. Controls the transition between regimes:

- linear (low-X)
- nonlinear (high-X)

Additionally:

- high values of X are associated with:
- high energy
- strong effective curvature
- extreme regions of the system

X measures the degree of microscopic activity in the universe; equivalently, X corresponds to the intensity of variation of the fundamental field.

Appendix F: Cosmological Perturbations

F.1 Field expansion

Consider a decomposition of the effective field around a homogeneous background:

$$Z(x,t) = Z_0(t) + \delta Z(x,t)$$

where:

- $\left(Z_0(t)\right)$: background solution (homogeneous)
- $\left(\delta Z(x,t)\right)$: small perturbation

It is assumed that:

$$|\delta Z| \ll 1$$

which allows the dynamics to be linearized.

F.2 Background equation

The background field satisfies the equation of motion obtained from the Lagrangian:

$$\ddot{Z}_0 + 3H\dot{Z}_0 + V'(Z_0) = 0$$

where (H) is the cosmological expansion rate.

F.3 Linearization of the field equation

Starting from the complete equation of the model, we substitute:

$$Z = Z_0 + \delta Z$$

and expands to first order in (δZ) .

The potential is expanded as:

$$V'(Z) \approx V'(Z_0) + V''(Z_0)\delta Z$$

F.4 Kinetic and regulatory terms

The kinetic invariant:

$$X = \nabla_\mu Z \nabla^\mu Z$$

is expanded as:

- background: (X_0)
- perturbation: linear terms in (δZ)

The logarithmic term:

$$-\ln\left(1 + \frac{X}{\Lambda^4}\right)$$

introduces an effective correction that modifies the propagation of perturbations.

In the perturbation regime, this defines an effective propagation velocity.

F.5 Perturbation equation

After expansion and canceling the background terms, the linear equation is obtained:

$$\ddot{\delta Z} + 3H\dot{\delta Z} - c_s^2\nabla^2\delta Z + V''(Z_0)\delta Z = 0$$

where:

- (c_s^2): effective sound speed induced by the regulator
- $\left(V''(Z_0)\right)$: effective mass of the field

F.6 Effective sound velocity

The logarithmic regulator modifies the kinetic term, resulting in:

$$c_s^2 = \frac{1}{1 + \frac{|\nabla Z|^2}{\Lambda^4}}$$

This implies:

- weak regime $(c_s^2 \approx 1)$
- strong regime $(c_s^2 \ll 1)$

F.7 Transformation to Fourier space

The perturbation is decomposed into modes:

$$\delta Z(x,t) = \int d^3\, k \delta Z_k(t) e^{ik\cdot x}$$

where:

$\nabla^2 \rightarrow -k^2$

F.8 Mode equation

Each mode evolves according to:

$$\delta \ddot{Z}_k + 3H\delta \dot{Z}_k + \left(\frac{c_s^2 k^2}{a^2} + m_Z^2\right)\delta Z_k = 0$$

where:

- $\left(m_Z^2 = V''(Z_0)\right)$

F.9 Inclusion of the full controller

In the complete model, the controller introduces a scaling factor:

$$\frac{k^2}{a^2} \rightarrow \frac{k^2}{a^2\left(1 + \frac{\zeta k^2}{\Lambda^4}\right)}$$

Therefore, the final equation is:

$$\delta \ddot{Z} + 3H\delta \dot{Z} + \left(\frac{k^2}{a^2\left(1 + \frac{\zeta k^2}{\Lambda^4}\right)} + m_Z^2\right)\delta Z = 0$$

F.10 Physical analysis

The equation describes:

Cosmological expansion

- $\left(3H\delta \dot{Z}\right)$
  e term → friction

Propagation

- term (k^2/a^2)

UV regulation

- factor:

$$\frac{1}{1 + \frac{\zeta k^2}{\Lambda^4}}$$

→ suppresses high-frequency modes

Effective mass

- controls structural growth

F.11 Regimes

Large scales $\left((\boldsymbol{k} \to \mathbf{0})\right)$

- structural growth
- Standard behavior

Small scales $\left((k \to \infty)\right)$

- dynamic suppression
- natural UV cutoff

The model introduces an internal mechanism where:

- the field regulates its own propagation
- no external regularizations are required
- the structure emerges with scale control

Appendix G: Effective Forms

APPENDIX G.1 Equivalent forms of the spectrum

Spectrum: Distribution of matter.

The power spectrum $P(k)$ describes the distribution of matter as a function of scale, quantifying how structures are organized in space.

$$\left[P(k) \sim \frac{e^{-k^2/k_*^2}}{(k^2 + m_Z^2)^{2-\epsilon}}\right]$$

- ($P(k)$): power spectrum
- (k): wavenumber (scale)
- (k_*): cutoff scale
- (m_Z): effective field mass
- (ϵ): spectral correction

In Fourier space:

- each$k$ mode represents a physical scale
- the dynamics of the field determine its amplitude

The spectrum arises from:

- propagation of perturbations
- effective mass
- high-frequency regulation

The power-law spectrum characterizes the distribution of matter, indicating that the system's structural configuration exhibits a functional dependence on the observational scale

In this context:

- large scales → dominate the distribution
- small scales → are suppressed

> **Large scales**

$k \to 0$

→ behavior dominated by

→ coherent structure

> **Intermediate scales**

→ transition controlled by the denominator

→ defines the shape of the spectrum

> Small scales
$k \to \infty$

→ the exponential factor dominates

→ Suppression of fluctuations

> Stability

- no UV divergences
- the spectrum is physically regular

Matter organizes itself according to the scale and dynamics of the field; equivalently, the structure of the universe is filtered by the Z field.

Appendix G.2 Equivalent forms of effective density

Effective density: Emergent dark matter.

The effective densityρ_Z describes an emergent mass contribution associated with the gradients of the field$Z$, interpreted as effective dark matter.

$$\left[\rho_Z = \rho_0 \left(\frac{|\nabla Z|^2}{\Lambda^4}\right)^{\alpha} \left(1 + \eta \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

- (ρ_Z): emergent density
- (ρ_0): density scale
- (α): base regime index
- (η): strong correction in the strong regime
- ($|\nabla Z|^2$): gradient intensity
- (Λ^4): fundamental scale

Mass depends on the dynamic regime. Generates effective mass

The expression has two contributions:

- **Base regime (galactic):**

$$\left(\frac{|\nabla Z|^2}{\Lambda^4}\right)^{\alpha}$$

- **Strong correction (clusters):**

$$\left(1 + \eta \frac{|\nabla Z|^2}{\Lambda^4}\right)$$

Mass is not fundamental; it depends on the dynamic regime of the field.

In this framework:

- small gradients → MOND-like behavior
- large gradients → effective additional mass

> Emerging dark matter

- does not require new particles
- arises from field dynamics

> Scale dependence

- density changes with the regime
- connects galaxies and clusters

> Mass formation

- gradients generate effective mass
- Gravity emerges from the structure of the field

Dark matter is a manifestation of the Z-field gradients; equivalently, mass is structured information.

Appendix G.3 Refined Form of the Spectrum

Power Spectrum: Power distribution of perturbations in Fourier space.

The power spectrum describes the distribution of amplitudes of field perturbations in Fourier space, characterizing the structure of the universe at different scales.

$$\left[P(k) \sim \frac{e^{-k^2/k_*^2}}{(k^2 + m_Z^2)^{2-\epsilon}}\right] [n_s \approx 0.96]$$

- ($P(k)$): power spectrum
- (k): wave number (scale)
- (k_*): cutoff scale
- (m_Z): effective field mass
- (ϵ): spectral correction
- (n_s): spectral index

Power distribution of the perturbations in Fourier space. Exponential cutoff at high (k), consistent with Planck.

The spectrum follows from the perturbation equation:

- the mass term → $(k^2 + m_Z^2)$
- the regulator → introduces exponential suppression

e^{-k^2/k_*^2}

This produces:

- standard behavior on large scales
- a smooth cutoff at small scales

The spectrum characterizes the structural distribution, showing that the system's power density exhibits an intrinsic functional dependence on scale

> Exponential cutoff

- suppression at high-k
- avoids UV divergences

> Consistency with observations

- $n_s \approx 0.96$
- consistent with CMB data (Planck)

> Mass dependence

- m_Z controls transition scale
- affects structure formation

> Natural regularization

- does not require an external cutoff
- emerges from the model

The cosmological spectrum is dynamically regulated; equivalently, small scales are suppressed by the dynamics of the Z field.

Appendix G.4 Phenomenological form of MOND

Galactic Dynamics and the MOND Regime

MOND: Modified weak gravity.

In the weak gravity regime, the dynamics of the system deviate from Newtonian behavior and follow a modified relationship between acceleration and matter:

$$[\, a = \sqrt{g_b\, a_0}\,]$$

- (a): observed acceleration
- (g_b): acceleration due to baryonic matter
- (a_0): characteristic acceleration scale

When the acceleration is small:
$g_b \ll a_0$
the dynamics cease to be linear and enter a modified regime where the system's response is sublinear.

Gravity changes in the weak regime:

The relationship between matter density and the acceleration profile undergoes a transition to a nonlinear regime

In this context:

- the gravitational response is amplified
- small sources generate larger effects

> **Strong regime**

$g_b \gg a_0 \Rightarrow a \approx g_b$
→ Newtonian gravity is restored

> **Weak regime**

$g_b \ll a_0 \Rightarrow a = \sqrt{g_b a_0}$

→ MOND behavior

> **Characteristic scale**

- a_0 defines the transition between regimes
- determines when the transition occurs

Gravity changes regime at low accelerations; equivalently, the dynamics depend on the acceleration scale.

Appendix H: Entropy

Appendix H.1 Alternative formulation of entropy

New entropic paradigm

Entropy: Information on the surface.

Entropy measures the information content of the system, which is encoded on its surface.

$$[S \propto A]$$

- (S): entropy
- (A): area

Surface information.

In the model:

- information is associated with the field gradients
- the maximum gradients are located on surfaces

This implies that the dominant contribution to entropy comes from the surface.

The system's information is localized at its boundary; the information resides on the surface.

> **Holographic scaling**

- entropy does not increase with volume
- it depends solely on the area

> **Localization of information**

- surfaces contain the state of the system

- the interior is emergent

The system’s information is encoded in its area; equivalently, entropy is a surface property.

Appendix H.2 Extended Entropy

Entropy: Information encoded in surfaces.

Entropy measures the informational content of the system, encoded in the variations of the field over surfaces.

$$\left[S_Z = \int dA \ \mathrm{In}\left(1 + \frac{|\nabla Z|^2}{\Lambda^4}\right)\right]$$

- (S_Z): entropy
- (dA): area element
- ($|\nabla Z|^2$): structural field strength
- (Λ): fundamental scale

Information encoded in surfaces. Measures information. Information $\propto$ area.

Entropy is constructed from:

- field gradients → encode information
- integration over surfaces → localizes the information

The logarithmic term:

- regulates the contribution
- introduces saturation in extreme regimes

The system's information is localized on surfaces: The information is proportional to the area.

In this framework:

- volume is not the primary source of information
- borders concentrate the informational structure

> Scaling with area

- entropy increases with surface area
- not with volume

> Role of gradients

- greater → more information
- regions with intense changes dominate

> Natural regulation

- The log function prevents divergences
- introduces an informational limit

> Geometric interpretation

- information is associated with spatial structures
- surfaces encode the state of the system

The system’s information is encoded in its surfaces; equivalently, the field gradients determine the entropy.

S_Z entropy measures the informational content of the system, where information is encoded in the gradients of the Z field.

$$\left[S_Z = \int d\,A \ \mathrm{In}(1 + |\nabla Z|^2/\Lambda^4)\right]$$

- (S_Z): entropy
- ($|\nabla Z|^2$): gradient intensity
- (Λ): fundamental scale

The following correspondence is established:

información $\equiv$ $|\nabla Z|^2$

and is integrated over surfaces to capture the total contribution of the system.

The logarithmic term:

- regularizes the information
- introduces saturation in intense regimes

The system's information is determined by variations in the field; the information is given by its gradients.

In this framework:

- uniform regions → low information
- regions with variation → high information

> Information coding

- the gradients contain all the information
- the structure of the system lies in the variations

> Scale dependence

- Λ l scale sets the threshold
- regulates informational intensity

> Saturation

- The log prevents divergences
- limits the maximum information

Physical information resides in field variations; without gradients, there is no information.

Appendix H.3 Equivalent form of N_{Local}

Equivalently, in terms of the deviation($\phi = Z - 0.5$):

$$\left[N_{\text{local}} \frac{\phi^2}{\Lambda^4, l_P^2} \right]$$

- (N_{local}): local degrees of freedom
- (A): area of the region
- (l_P): Planck length
- ($|\nabla Z|^2$): gradient intensity, correlation density (field gradient)
- (Λ): characteristic scale of the system
- ($\phi \equiv Z - 0.5$): deviation from equilibrium

The local information is proportional to the square of the deviation from the equilibrium state. This defines the effective number of degrees of freedom accessible in the region.

In this framework, geometric size alone does not determine the physical information: what matters is the magnitude of the deviation and the intensity of local correlations.

This expression suggests that the effective number of local degrees of freedom is controlled by the correlation density rather than by purely geometric measures.

Appendix I: Thermodynamic Gravity

Appendix I.1 Einstein's Thermodynamic Derivation

Gravity is an equation of state, not a fundamental force. It imposes local thermodynamic equilibrium. Gravity emerges from the thermodynamics of the Z field.

We start from the principle:

change in entropy ∼ energy flux

Imposing local equilibrium:

- the system's entropy is constant
- energy and information are in balance

Given that:

- entropy depends on geometry (area)
- energy depends on the material content

the condition:

$\delta S_Z \sim \delta E$

imposes a relationship between geometry and energy, which leads to:

$G_{\mu\nu} = 8\pi G\, T_{\mu\nu}$

Gravity is not fundamental: gravity is an equation of state

In this framework:

- geometry responds to energy
- spacetime emerges from equilibrium

> Emergent gravity

- is not a fundamental force
- it is a macroscopic manifestation

> Information–energy relationship

- entropy controls geometry
- energy induces curvature

> Consistency with relativity

- exactly reproduces Einstein’s equations
- without postulating fundamental geometry

> Conceptual unification

- Z field → information
- information → entropy
- entropy → geometry
- geometry → gravity

Gravity is a thermodynamic phenomenon of spacetime, while curvature reflects the system’s response to its information.

Appendix I.2 Variational Principle

The geometry of spacetime emerges as a stationary solution of the complete system.

Starting from the action:

$S = \int d^4\, x\, \sqrt{-g}\left[\frac{1}{16\pi G} R + \mathcal{L}_Z\right]$

a variation is performed with respect to the metric $g_{\mu\nu}$:

$\delta S \;=\; 0$

This implies:

1. Variation of the geometric term:

$\delta\left(\sqrt{-g}R\right) \;\Rightarrow\; G_{\mu\nu}$

2. Variation of the field term:

$\delta\left(\sqrt{-g}\,\mathcal{L}_Z\right) \;\Rightarrow\; T_{\mu\nu}^{(Z)}$

Combining both results yields the dynamic equation of the system.

which leads to equations of the form:

$G_{\mu\nu} = 8\pi G\, T_{\mu\nu}^{(Z)}$

This principle establishes that:

- geometry is not imposed, but rather emerges dynamically
- spacetime conforms to the system's configuration

Geometry is a solution to the entire system

Within this framework:

- curvature responds to the structure of the field
- the global dynamics are self-consistent

> Emergence of geometry

$g_{\mu\nu}$'s metric is not fundamental, but is determined as a solution of dynamic equilibrium.

> Matter–geometry coupling

The hZ ic field acts as a gravitational source through its energy-momentum tensor.

> Recovery of general relativity

In Z regimes where it is smooth:

- the standard Einstein equations are recovered
- the model agrees with GR

> Corrections in extreme regimes

Under high-energy conditions:

- nonlinear effects appear
- gravitational dynamics are modified
- curvature is regulated

Spacetime is not postulated, but rather determined; equivalently, geometry is a consequence of the variational principle.

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