Article

Continuous Field Dynamics and the Dark Matter Effect: A First-Principles Approach

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Abstract

The dynamics of galaxies have shown systematic deviations for decades [9–12] from the gravitational behavior expected from visible baryonic matter alone. These effects are usually described either by introducing an additional dark matter component or by modifying the laws of gravity [4, 7]. In this work, a different approach is pursued. The dark matter effect is interpreted not as additional matter, but as the field response of a continuous medium. Within the framework of the Universal Quantum Foam Hypothesis, radiation is understood as a spherical stress front propagating at the speed of light, locally deforming and exciting the field. The strength of this field deformation depends on the frequency and energy density of the radiation involved. High-energy baryonic sources may therefore produce stronger local field excitations than isotropic background radiation, while the macroscopic effect is governed by the total field response. This view is consistent with general relativity [1], where energy content contributes to curvature, but here the effect is interpreted as an organized field response of a continuous field medium. The additional gravitational acceleration does not arise from a separate matter density, but from the nonlinear, baryonically organized, and saturation-limited response of the field. The derived equation is not based on an empirical fit, but follows from the underlying physical assumptions. In this framework, field excitation remains present even in baryon-poor systems, but without sufficient baryonic anchoring it is not organized on macroscopic scales. Ultra-diffuse galaxies therefore appear as systems with a weak or apparently absent dark matter effect, although field excitation remains present.

1. Introduction

> "A space without physical properties appears hardly conceivable."
> — paraphrased from Albert Einstein

Since the first studies of galactic rotation curves, it has been known that the observed dynamics of many galaxies cannot be fully explained by visible baryonic matter alone [9–12]. This becomes particularly evident in spiral galaxies, whose outer regions exhibit significantly higher rotational velocities than expected from the baryonic mass distribution. Similar indications arise from observations of gravitational lensing in galaxy clusters [6]. The dominant explanations today either assume an additional, not directly observable matter component or describe the dynamics through modifications or emergent interpretations of gravity [3–5, 7]. Despite their successes, however, it remains unclear whether the observed effect is truly caused by additional matter or whether it points to a still incompletely understood property of the physical background medium.

The question of what is actually meant by this field therefore forms a central aspect of the present approach. The following introduction is therefore intentionally more detailed, as the conceptual understanding of the field framework forms a central basis for the physical interpretation of the model developed in this work. Within the framework of the Universal Quantum Foam Hypothesis (UQSH), the field is not treated as an empty background, but as a fundamental continuous medium from which physical processes emerge. In this picture, physical space possesses a real intrinsically dynamical structure and does not represent a passive background. Matter, radiation, and gravitation are therefore not interpreted as fundamentally separate entities, but as different organizational and coupling states of the same underlying field medium. The field is mainly characterized by two complementary properties. Whenever energy is introduced or bound matter states form, local field stresses arise, while the field simultaneously tends toward stress relaxation. Physical processes emerge from the interplay between field stress and internal field relaxation. This medium is capable of carrying, storing, and organizing energy, stress, and field deformations across large scales. At the same time, the field medium itself does not appear directly observable. Direct observation of such a field is neither necessary nor unusual within physics. Many fundamental structures are not observed directly, but inferred exclusively through their dynamical effects. Gravity itself is invisible and is described only through orbital motion, acceleration, or lensing effects. Electric and magnetic fields are likewise not directly seen, but recognized through their influence on charged particles and matter. Even spacetime curvature in general relativity is not directly observed, but parametrized through its effects on light propagation, temporal evolution, and gravitational dynamics. Similarly, in quantum field theory, fundamental fields appear only through their excitations and coupling effects. Within the UQSH framework, the same physical logic is applied to large-scale field organization. The dynamical structure of the field medium is not observed directly, but parametrized through its physical effects. Observable quantities such as gravitational acceleration, rotational dynamics, lensing effects, or stable matter states appear as manifestations of underlying field organization. The essential point is that field excitation alone does not yet generate a stable macroscopic dark matter effect. Only when this field stress becomes spatially organized through baryonic structures does a coherent additional gravitational response emerge. At the same time, the field possesses a limited local absorption capacity, referred to in the following as saturation. Additional field stress therefore cannot be concentrated locally without bound, but must instead be redistributed over larger scales.

Radiation is interpreted as a spherical stress front propagating at the speed of light and locally deforming and exciting the field. Within the UQSH framework, the speed of light is not interpreted merely as a property of electromagnetic radiation, but as the fundamental propagation and reaction speed of the field medium itself. Every local field excitation generates a reorganization of the medium that propagates causally at the speed of light. The reaction of the field therefore occurs fundamentally in a spherical manner, since a local change in stress within a continuous medium cannot preferentially propagate only in specific directions. Radiation therefore appears in this picture as the visible manifestation of a general internal reaction dynamics of the field.

The resulting deformations generate local field-curvature stresses, which within the UQSH framework are understood as the field-mechanical description of gravitational interaction and are referred to in the following simply as field stress. Since baryonic sources continuously generate such stress fronts and these permanently overlap, a persistently excited field structure emerges. Matter itself is not regarded here as a fundamentally independent substance. Instead, stable baryonic states appear as bound organizational forms of the field medium. Radiation corresponds to propagating field deformations, while gravitation is interpreted as large-scale stress organization within the same medium. Most field dynamics remain below the threshold required for stable baryonic binding and therefore do not appear directly as visible matter, even though gravitational effects continue to arise.

The present work does not claim to provide a complete theory of all physical processes. Instead, it should be understood as a field-mechanical and ontological interpretation of observable dynamics combined with an effective mathematical description of the dark matter effect. The aim is not to replace established physics in a general sense, but to formulate a consistent interpretation of observed gravitational excesses within a continuous field framework.

On the basis of these assumptions, an effective field equation is formulated in which the dark matter effect does not appear as an additional matter density, but as the consequence of a baryonically organized and saturation-limited field response. The equation is not fitted to observational data, but derived directly from the underlying physical assumptions. The present approach deliberately focuses on the fundamental formulation of this mechanism. Its goal is to provide a physically transparent and conceptually simple description of the dark matter effect, interpreting it as a property of continuous field dynamics rather than as the consequence of an additional matter component.

This introduction describes the dynamics and organizational structure of the field medium, but does not claim to fully explain its ultimate origin. In particular, the origin of the field itself, its possible age, its size, whether it is finite or infinite, as well as the initial interaction between energy input and field response remain open questions within the UQSH framework. The present work therefore focuses deliberately on the observable dynamics of organized field states rather than on a complete cosmological theory of origin.

2. Derivation of the Pure Dark Matter Effect

2.1. Starting Point

The starting point is a continuous field medium whose state is described by an effective potential $\phi(\mathbf{x}, t)$. The observable gravitational acceleration follows from the gradient of this potential:

$$\mathbf{g}(\mathbf{x}, t) = -\nabla\phi(\mathbf{x}, t). \tag{1}$$

Baryonic matter provides the known gravitational contribution ϕ_{bar}. In addition, the field is continuously excited by radiation. In the UQSH framework, this radiation is understood as a stress front propagating at the speed of light and locally deforming the field.

2.2. Radiation-Induced Field Excitation

The field excitation arises from the superposition of many such stress fronts. The effective field response is written as

$$\Phi_{\mathrm{rad}}(\mathbf{x}, t) = \int d^3x' \, \frac{Q_{\mathrm{rad}}\left(\mathbf{x}', t - \frac{R}{c}\right)}{4\pi R^2} \, \mathcal{S}_\phi(\mathbf{x}, t) \, O_{\mathrm{bar}}(\mathbf{x}, t), \quad R = |\mathbf{x} - \mathbf{x}'|. \tag{2}$$

Here, Q_{rad} describes the local source strength of radiation-induced field excitation, while the factor $1/(4\pi R^2)$ accounts for the spherical propagation of the stress fronts.

The functions $\mathcal{S}$ and O describe local saturation and baryonic organization of the field response and are introduced below.

$$\mathcal{S}_\phi(\mathbf{x}, t) = \mathcal{S}\left(\frac{|\nabla\phi(\mathbf{x}, t)|}{S_\phi}\right), \qquad O_{\text{bar}}(\mathbf{x}, t) = O\left(\frac{\rho_{\text{bar}}(\mathbf{x}, t)}{\rho_A}\right). \tag{3}$$

2.2.1. Frequency and Energy Dependence of Field Excitation

In the UQSH framework, every form of radiation deforms the field medium. The strength of this deformation, however, depends strongly on the frequency and energy density of the radiation involved. High-frequency and energy-rich radiation produces much stronger local field deformations than weak or low-frequency background radiation. Radiation processes originating directly from baryonic sources therefore lead to substantially stronger field excitations than isotropic background radiation entering a galaxy. At the same time, isotropic background radiation remains field-active. Every stress front contributes to the local stress gradient of the field, even if its contribution is small. Field excitation is therefore present throughout the field medium and does not vanish completely even in baryon-poor regions. The observable field structure emerges from the continuous superposition of these differently weighted excitations. Low-frequency and high-frequency contributions overlap permanently, with the high-frequency and energy-dense components dominating the macroscopic field organization. This view is broadly consistent with general relativity [1], in which energy and radiation contribute to spacetime curvature through the energy-momentum tensor. The difference lies mainly in the interpretation: in the UQSH framework, the gravitational effect appears as an organized field response of a continuous field medium to the superposition of real field deformations.

2.3. Local Saturation of the Field Response

The field medium has only a limited local capacity to absorb stress. Field stress therefore cannot be concentrated without limit in a small region. Once a certain local load is exceeded, the field responds increasingly in a saturated way. To describe this transition, the dimensionless saturation function

$$\mathcal{S}(z) = \frac{z^m}{1 + z^m}, \qquad 0 \le \mathcal{S}(z) < 1, \qquad z = \frac{|\nabla\phi|}{S_\phi} \tag{4}$$

is introduced. For small field gradients ($z \ll 1$), the function grows approximately as z^m. As the field stress increases, however, the function approaches a limiting value:

$$\mathcal{S}(z) \to 1. \tag{5}$$

The field excitation does not disappear; rather, its further local amplification becomes increasingly limited. Additional field stress can then no longer be fully absorbed locally. How quickly this transition occurs depends on the structure of the incoming field excitation. The exponent m describes the sharpness of the transition between linear amplification and saturated field response. High-frequency and energy-dense radiation produces stronger local field deformations and reaches the saturation scale more quickly than weak or low-frequency background excitation. In this case the transition is steeper.

Low-frequency or isotropically distributed background radiation, by contrast, leads to a softer and more spatially extended saturation. The parameter m is therefore not to be understood as a fundamental constant, but as an effective description of the specific field excitation. More generally, one may write

$$m = m(\nu, u_{\text{rad}}), \tag{6}$$

where ν denotes the characteristic frequency of the radiation and u_{rad} its energy density. The saturation function then takes the more general form

$$\mathcal{S}(z; \nu, u_{\text{rad}}) = \frac{z^{m(\nu, u_{\text{rad}})}}{1 + z^{m(\nu, u_{\text{rad}})}}, \quad z = \frac{|\nabla \phi|}{S_\phi}. \tag{7}$$

The basic structure of the saturation remains unchanged. What differs is how quickly a given radiation-induced excitation drives the field into the saturated regime.

2.4. Baryonic Organization

Field excitation alone does not yet produce a stable macroscopic gravitational effect. The decisive question is whether the resulting field stress can be spatially organized and stabilized over larger scales. In the UQSH framework, baryonic matter acts as a structural anchor. It bundles and stabilizes the existing field stress, allowing a coherent macroscopic field structure to form.

To describe this transition, the baryonic organization function

$$O(u) = \frac{u}{1 + u}, \qquad 0 \leq O(u) < 1, \quad u = \frac{\rho_{\text{bar}}}{\rho_A} \tag{8}$$

is introduced, where ρ_{bar} is the local baryonic density and ρ_A is a characteristic organization scale. At low baryonic density, the field excitation remains largely local and unordered. As baryonic structure increases, the field stress becomes increasingly coherently organized and can manifest macroscopically as an additional gravitational effect. The observable dark matter effect therefore does not arise from field excitation alone, but only from its baryonic organization.

Thus,

$$\boxed{\text{field excitation} \neq \text{dark matter effect}} \tag{9}$$

$$\boxed{\text{dark matter effect} = \text{organized field excitation}} \tag{10}$$

2.5. Necessity of Nonlocal Redistribution

Local saturation of the field means that, beyond a certain load, additional field stress can no longer be fully absorbed within a small spatial region. In the UQSH framework, however, the dynamics of the field medium remain fundamentally active. A complete local collapse of the dynamics would correspond to an idealized singularity, and thus to a state in which no further internal field evolution would be possible. The field is therefore not treated as infinitely compressible, but as a medium with finite elasticity and relaxation behavior. Once the local absorption capacity is exceeded, excess field stress must be redistributed over larger scales. The field response then passes from purely local amplification into a spatially organized dynamics.

This nonlocal redistribution is described by an additional contribution to the effective potential:

$$\Phi_{\rm nl}(\mathbf{x},t) = \lambda_\phi \nabla \cdot \left[\mathcal{S}\left(\frac{|\nabla\phi|}{S_\phi} \right) \nabla \Phi_{\rm rad}(\mathbf{x},t) \right]. \tag{11}$$

The term $\Phi_{\rm nl}$ is not an additional ad hoc contribution, but follows directly from the saturation dynamics of the field medium. Since field stress cannot grow without limit locally, while at the same time remaining conserved, spatial redistribution necessarily occurs. $\Phi_{\rm nl}$ therefore describes the macroscopic organization of the field through the nonlinear redistribution of excess field stress.

2.6. The Physical Role of the Coupling η_ϕ

The strength of the local field excitation is described by the source term

$$Q_{\rm rad} = \eta_\phi \, \mathcal{L}_{\rm bar} \tag{12}$$

where $\mathcal{L}_{\rm bar}$ denotes the baryonic field emission.

In the UQSH framework, not every form of radiation acts on the field medium with the same strength. Different radiation components deform the field according to their frequency and energy density. High-frequency and energy-dense radiation produces much stronger local field deformations than weak or isotropically distributed background radiation. The source term $Q_{\rm rad}$ therefore describes the effective field-exciting power of baryonic processes and is, in general, frequency dependent. An effective representation can be written as

$$Q_{\rm rad} \sim \int d\nu \, w(\nu) \, L_{\rm em}(\nu) \tag{13}$$

where $L_{\rm em}(\nu)$ is the spectral baryonic emission and $w(\nu)$ describes the frequency-dependent strength of the field coupling. The observable field structure arises from the superposition of many such excitations. Low-frequency and high-frequency contributions overlap continuously, with high-frequency and energy-dense components dominating the macroscopic field organization. The present work primarily considers electromagnetic field excitation. Other possible contributions, such as gravitational waves or bound field stresses, are not treated further here. The quantity η_ϕ is not to be understood as a fundamental constant of nature. Rather, it describes an effective macroscopic coupling between baryonic emission and organized field stress. Since this coupling depends on the dynamics of the field medium, η_ϕ implicitly contains characteristic scales of the system, in particular the saturation scale S_ϕ and the redistribution scale λ_ϕ. A possible normalization of η_ϕ can be made using observable additional acceleration scales in galactic systems. This normalization, however, is not fundamental; it merely describes the macroscopic expression of the underlying field dynamics.

2.7. Characteristic Scales

The quantities introduced in this work, S_ϕ, ρ_A, λ_ϕ, and m, are not understood as fundamental constants of nature. Rather, they describe effective macroscopic properties of the field medium. Their exact values depend on the dynamical state of the particular system. Nevertheless, on galactic scales there are characteristic ranges within which stable field organization occurs. For the galactic regimes considered in this work, the following preliminary effective orders of magnitude are obtained:

$$S_\phi \sim 10^3 \ (\mathrm{km/s})^2/\mathrm{kpc}, \tag{14}$$
$$\rho_A \sim 10^6 - 10^7 \ M_\odot/\mathrm{kpc}^3, \tag{15}$$
$$\lambda_\phi \sim 2 - 6 \ \mathrm{kpc}, \tag{16}$$
$$m \sim 1 - 2. \tag{17}$$

These values should therefore not be interpreted as universal constants, but as effective astrophysical scales of the field medium.

2.8. Total Equation

The effective potential of the dark matter effect is composed of the local field excitation and its nonlocal redistribution:

$$\Phi_{\mathrm{DM,eff}} = \Phi_{\mathrm{rad}} + \Phi_{\mathrm{nl}}. \tag{18}$$

The additional gravitational acceleration follows as

$$\mathbf{g}_{\mathrm{DM}} = -\nabla\Phi_{\mathrm{DM,eff}}. \tag{19}$$

For the observable dynamics this gives

$$\boxed{\mathbf{g}_{\mathrm{obs}} = \mathbf{g}_{\mathrm{bar}} + \mathbf{g}_{\mathrm{DM}}} \tag{20}$$

3. Physical Consequences

In the UQSH framework, the dark matter effect emerges from the interplay of four fundamental properties of the field medium:

- causal field excitation by propagating and isotropic stress fronts,
- baryonic organization of this field excitation,
- limited local absorption capacity of the field,
- and nonlinear redistribution of excess field stress.

The derived equation is therefore not based on a direct fit to observational data, but follows from these physical mechanisms themselves.

3.1. Prediction for Ultra-Diffuse Galaxies

The role of baryonic organization leads directly to a testable consequence for systems with very low baryonic density. Since field excitation remains present throughout the field medium in the UQSH framework, a nonzero field stress also persists in baryon-poor systems. Without sufficient baryonic structure, however, this field excitation remains largely unordered.

For ultra-diffuse galaxies one therefore has

$$\rho_{\text{bar}} \ll \rho_A \quad \Rightarrow \quad O \approx 0. \tag{21}$$

In this regime, the field excitation still contributes to the local field state, but does not form a stable macroscopic field organization. The effective dark matter contribution is therefore strongly suppressed:

$$O \approx 0 \quad \Rightarrow \quad \Phi_{\text{DM,eff}} \ll \Phi_{\text{rad}}. \tag{22}$$

The observable dark matter effect in such systems therefore appears weak or apparently absent, even though field excitation remains present.

This leads to several direct predictions:

- Ultra-diffuse galaxies do not show a stable global dark matter effect.
- Local deviations from purely baryonic dynamics may still occur.
- The strength of these deviations correlates with the local baryonic structure.

This interpretation differs fundamentally from classical halo models, in which the dark matter effect is largely treated as independent of the specific baryonic organization.

3.2. Physical Interpretation of the Limiting Cases

The formal limiting cases of the field equation have a clear physical meaning within the UQSH framework. It is important, however, that not every mathematically formulated limit is physically realizable.

Limit $S_\phi \to \infty$ (No Saturation) A state without saturation is not physically realizable within the UQSH framework. Field stress remains fundamentally limited by the properties of the field medium. Without this limitation, additional field stress would become locally concentrated without bound. Local field regions could continuously absorb energy without ever reaching a stable state. Over time, this would lead to an unstable singularity in which increasingly larger field stress becomes concentrated into increasingly smaller regions.

The existence of a saturation limit is therefore a necessary condition for the stability of the field medium. Indications of such saturation-like states can be found in highly condensed astrophysical structures. These include not only black holes, but also compact galactic cores and strongly concentrated central regions of gravitationally bound systems. Within the UQSH framework, such regions are not interpreted as infinitely collapsing point structures, but as regions of maximally organized field stress in which additional local amplification becomes increasingly suppressed.

In such regimes, field dynamics therefore no longer primarily proceed toward further local condensation, but increasingly toward large-scale reorganization and redistribution of field stress. This may be particularly related to observed transitions between different central density and dynamical regimes, as empirically derived in [13] within the framework of a bimodal regime structure of galactic rotation curves. In this picture, the saturation limit acts as a stabilizing mechanism against unlimited local field concentration.

Limit $\lambda_\phi \to 0$ (No Redistribution) This limiting case is also not physically realizable within the UQSH framework. Once the local field response saturates, additional field stress cannot remain completely local. At the same time, the dynamics of the field must be preserved. This necessarily leads to a spatial redistribution of the excess field stress. A vanishing redistribution scale would mean that field stress could neither be stored locally nor distributed spatially. The field would then enter a contradictory state. The existence of a nonzero redistribution is therefore a direct consequence of the saturation dynamics of the field medium.

Limit $\eta_\phi \to 0$ (No Coupling) A completely vanishing coupling term ($\eta_\phi \to 0$) is likewise not physically realizable in the UQSH framework. The field, interpreted within the UQSH framework as qu-foam, forms the fundamental continuous medium from which physical processes emerge. The field medium has intrinsic dynamics that persist even in regions without baryonic structure. It follows that there is no region of the universe completely free of field excitation. Even in baryon-poor regions, a minimal field activity therefore remains, for example in the form of isotropic background excitations such as the cosmic microwave background.

Limit $\rho_A \to 0$ (No Baryonic Organization) In the limit of vanishing baryonic organization, field excitation remains present but cannot form a stable macroscopic structure. The field response therefore stays largely local and unordered. In this regime, stress fronts still contribute to the local field state, but the collective organization required for a stable dark matter effect no longer emerges. This behavior corresponds to extremely baryon-poor systems or large-scale void regions, where field excitation persists but macroscopic organized field amplification becomes strongly suppressed.

4. Conclusion

In this work, the dark matter effect has been described as the field response of a continuous medium. The starting point is the interpretation of radiation as a spherical stress front propagating at the speed of light, locally deforming and exciting the field. In this picture, the additional gravitational acceleration does not arise from a separate matter component, but from organized and nonlinearly redistributed field stress. The analysis suggests that the observable dark matter effect emerges from the interplay of three basic mechanisms:

$$\textbf{DM effect} \sim \text{radiation} \times \text{baryonic organization} \times \text{saturation-limited redistribution} \tag{23}$$

The derived field equation was not fitted to observational data, but developed from the underlying physical assumptions. For real astrophysical systems, however, an effective macroscopic description is required, since observable dynamics always result from collective field organization across many scales. The dark matter effect therefore appears as an emergent property of a baryonically organized field medium, rather than as an additional form of matter. At the same time, the model leads to several direct astrophysical consequences. These include the dependence of field amplification on the frequency and energy density of radiation, the possible weakening of the effect in baryon-poor systems, and the role of nonlocal redistribution in saturated field states. The present work is intended as the theoretical basis of this approach. A detailed application to observable relations such as the Radial Acceleration Relation (RAR), the Mass Discrepancy Acceleration Relation (MDAR), and different dynamical regimes is left to future work.

Field-based and emergent interpretations of gravity have been discussed in different theoretical contexts [2, 3, 5]. The present work follows a distinct approach based on a continuous field medium and saturation-driven field organization.

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