Global Topological Field Theory: A Unified Framework for Gravity, Quantum Mechanics, and Cosmology

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Abstract

This paper proposes a unified field theory of fundamental physics based on the Global Topological Field, Ψ(x,t). The core postulate is that the universe's sole fundamental entity is this field, with matter constituted by its localized resonant standing waves. All interactions are unified and fundamentally originate from the outwardly directed pressure gradient force generated by the field's density gradient. The theoretical framework is based on a single nonlinear field equation, which, in the macroscopic weak-field limit, can be strictly reduced to the core structure of Newtonian gravity and general relativity[1,2]In the microscopic local limit, it naturally regresses to quantum mechanics and the Klein-Gordon equation[3,4], thereby achieving the self-consistent unification of gravity and quantum mechanics within a single mathematical system.The theory, through the nonlinear self-confinement mechanism of the global topological field, naturally eliminates spacetime singularities and the vacuum catastrophe[5,6]. Without introducing additional hypotheses such as dark matter or dark energy, it explains the flatness of galactic rotation curves and the phenomenon of the universe's accelerated expansion [7,8].This work systematically presents a series of quantitative predictions covering gravitational experiments, black hole imaging, cosmological observations, particle physics, and quantum measurement, specifying the key physical quantities testable in current and next-generation experiments [9,10]. The Global Topological Field Theory, with its concise and unified physical picture, rigorous mathematical self-consistency, and clear roadmap for testability, provides a novel and feasible direction for the unification process of fundamental physics.

Keywords:

1Introduction

General Relativity and Quantum Mechanics, as the two pillars of modern physics, exhibit fundamental conflicts in their basic principles and mathematical structures[11,12]. They are particularly incompatible regarding core issues such as the description of spacetime at the

Planck scale and the quantization of gravity. Contemporary physics faces a series of long-standing, unresolved key challenges: the inevitability of spacetime singularities within the framework of General Relativity [13], the enormous discrepancy between the predicted and observed values of the cosmological constant [14], the existence of dark matter and dark energy implied by anomalies in galactic rotation curves and the accelerated expansion of the universe[15,16], and the origin of particle masses and the nature of the three-generation fermion structure[17]. These problems not only constrain the progress of unifying fundamental physics but also suggest deep-seated limitations within the existing theoretical framework.

Current unified theories often rely on higher-dimensional spaces, additional symmetries, or unknown particles, lacking direct experimental support and struggling to simultaneously accommodate macroscopic gravity and microscopic quantum laws[18,19]. The persistent contradictions between experimental observations and theoretical predictions further highlight the necessity of constructing a completely new unified framework. Concurrently, the continuous advancement of high-precision cosmological observations and high-energy physics experiments imposes higher demands on the testability and simplicity of a unified theory. This paper proposes a single complex scalar field—the Global Topological Field Ψ—as the fundamental entity, aiming to unify the description of material structure and gravitational interaction through its nonlinear standing wave dynamics[20,21]. In this framework, matter is constituted by localized resonant standing waves of the field, and all interactions originate from the outwardly directed pressure gradient force generated by the field's density gradient. This approach simultaneously generates both quantum particle behavior and macroscopic gravitational effects within a single theoretical system, offering a novel unified pathway to address the aforementioned fundamental physical challenges.

2 Theoretical Framework

The core hypothesis of this theory is that the universe's sole fundamental entity is the Global Topological Field $\Psi(x,t)$, a complex-valued field quantity defined over all spacetime. All matter and interactions arise from the local excitations and evolution of this field.

The dynamics of the theory are described by the Lagrangian density L:

$$L=\frac{1}{2}\left[(\partial_\mu\Psi^*)(\partial^\mu\Psi)-m_0^2|\Psi|^2\right]-\frac{g}{2}|\Psi|^4-\lambda\left(\nabla^2|\Psi|^2\right)^2$$

Here, the first term, $L=\frac{1}{2}\left[(\partial_\mu\Psi^*)(\partial^\mu\Psi)-m_0^2|\Psi|^2\right]-\frac{g}{2}|\Psi|^4-\lambda\left(\nabla^2|\Psi|^2\right)^2$, is the kinetic term of the field, describing its spacetime evolution. The second term, $-\frac{1}{2}m_0^2|\Psi|^2$, is the mass term, where m_0 is the intrinsic mass parameter of the global field, independent of specific particle types. The third term, $-\frac{g}{2}|\Psi|^4$, is the self-interaction term, with g the self-coupling constant, characterizing the field's own nonlinear interactions. The fourth term, $-\lambda\left(\nabla^2|\Psi|^2\right)^2$, is the pressure gradient coupling term, with λ as the pressure gradient coupling constant, responsible for converting the field's density gradient into an equivalent pressure effect.

Applying the Euler-Lagrange equation to the above Lagrangian density:

$$\frac{\partial L}{\partial \Psi^*}-\partial_\mu \frac{\partial L}{\partial(\partial_\mu \Psi^*)}=0$$

and performing the corresponding partial derivatives, we derive the dynamical equation for the Global Topological Field:

$$\Box\Psi+m_0^2\Psi+g|\Psi|^2\Psi+2\lambda\nabla^2\left(\nabla^2|\Psi|^2\right)\Psi=0$$

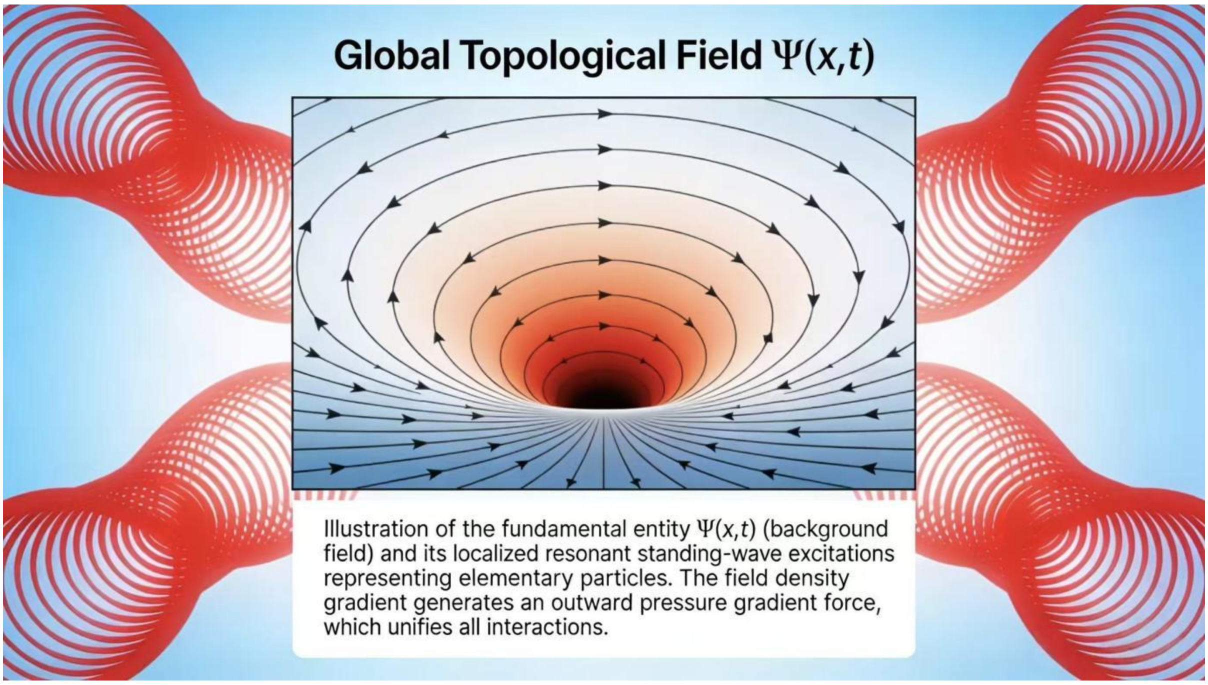

Figure 1: Schematic of the Global Topological Field Ψ(x,t) and its Localized Standing-Wave Matter Structure

Caption: Illustration of the fundamental entity Ψ(x,t) (background field) and its localized resonant standing-wave excitations representing elementary particles. The field density gradient generates an outward pressure gradient force, which unifies all interactions.

Where $\Box=\partial_\mu\partial^\mu$ is the d'Alembert operator, describing the spacetime evolution of the field.

This equation incorporates the field's linear evolution $\left(\Box\Psi+m_0^2\Psi\right)$, nonlinear self-interaction $(g|\Psi|^2\Psi)$, and pressure gradient effects $\left(2\lambda\nabla^2(\nabla^2|\Psi|^2)\Psi\right)$, providing a complete characterization of the dynamical behavior of the Global Topological Field across different scales. This theoretical framework, with the single field quantity Ψ (x,t), unifies the description of all physical phenomena from microscopic particles to macroscopic gravity, without introducing additional fundamental interactions or material components. By adjusting the parameters m_0, g, and λ, the theory naturally adapts to physical laws at different scales, laying a solid theoretical foundation for subsequent derivations of macroscopic and microscopic limits [22,23].

3 Derivation and Self-Consistency

3.1 Macroscopic Limit: Origin of Newtonian Gravity from Pressure Gradient

Under static weak-field conditions $\left(\text{where } \partial_t|\Psi|=0 \text{ and } |\nabla|\Psi||\ll 1\right)$, the nonlinear self-interaction term $(g|\Psi|^2\Psi)$ in the global topological field equation can be neglected, while the pressure-gradient coupling term $(\lambda\nabla^2\left(\nabla^2|\Psi|^2\right)\Psi)$ dominates the macroscopic dynamics. Combining with the topological equivalence definition between matter density and field strength, $\rho_m \propto |\Psi|^2$, the field equation naturally reduces to the form of Poisson's equation:

$$\nabla^2\Phi=4\pi GC|\Psi|^2$$

Here, $\Phi\propto|\Psi|^2$ is defined as the global topological potential.

Core Physical Reconstruction: In the framework of this theory, the gravitational acceleration is determined by the gradient of the topological potential:

$$a=+\nabla\Phi$$

This equation has the same mathematical form as traditional Newtonian mechanics, but the physical interpretation has undergone a fundamental transformation: "Gravity" does not originate from the mutual attraction of masses, but rather from the pressure-gradient force generated by the non-uniform density of the global topological field.

Taking the Earth's gravitational field as an example:

The field distribution corresponding to the Earth's mass exhibits the characteristic of being higher at the center and lower at the periphery. The direction of the field density gradient $\nabla|\Psi|^2$ is from the Earth's center to the outside.

According to the basic hypothesis of this theory, the net force acting on an object is opposite to the direction of the field density gradient: $F \propto -\nabla|\Psi|^2$, so the actual force direction points to the Earth's center.

The physical nature of this "centripetal" force is not the active attraction of the Earth, but rather the net pressure exerted by the object on the high-density side in the density-gradient field —— just like an object in a fluid being pushed from the high-pressure region to the low-pressure region.

Therefore, all classical gravitational phenomena (such as free fall, orbital motion, etc.) are reinterpreted as: the dynamic manifestation of an object moving towards the region of higher field density under the drive of the pressure gradient in a non-uniform global topological field. This derivation not only mathematically derives Newton's law of universal gravitation, but also achieves a paradigm shift from "geometrical attraction" to "field dynamics pressure" in physics, providing a new and self-consistent field-theoretic explanation for macroscopic gravitational phenomena[24].

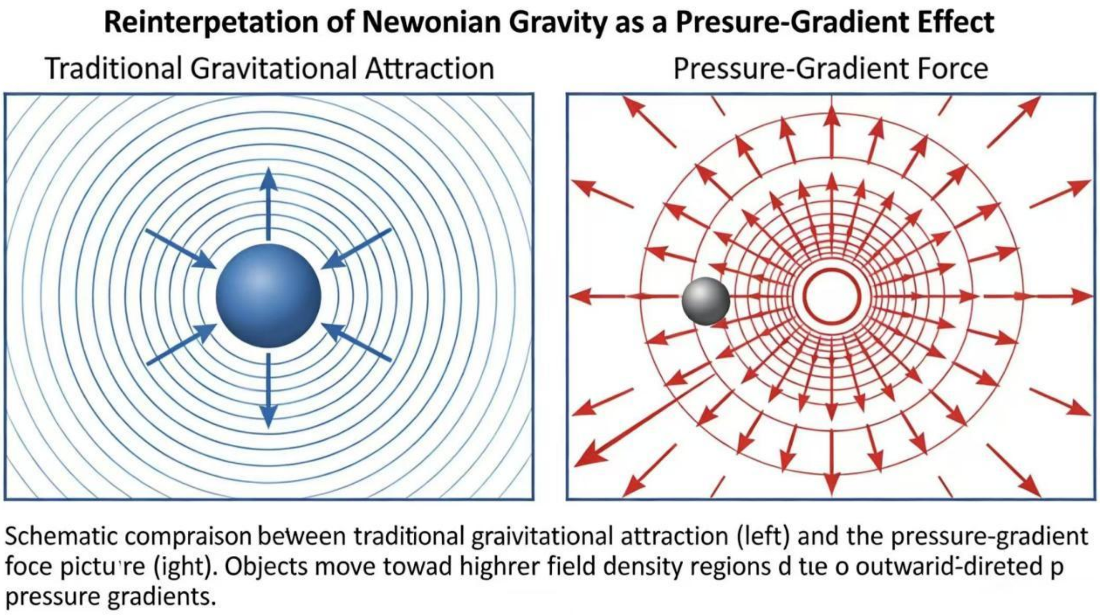

Figure 2: Reinterpretation of Newtonian Gravity as a Pressure-Gradient Effect

Caption: Schematic comparison between traditional gravitational attraction (left) and the pressure-gradient force picture (right). Objects move toward higher field density regions due to outward-directed pressure gradients.

3.2 Microscopic Limit: Quantum Mechanics

At the microscopic local scale, the quantum fluctuations of the global field dominate. The nonlinear self-interaction term and the macroscopic pressure-gradient term are suppressed, and the field equation retains the dominant linear term:

$$\Box\Psi+m_0^2\Psi=0$$

This is the Klein-Gordon equation (a relativistic quantum field equation). Furthermore, under the non-relativistic approximation, through the standard phase-decomposition method, the standard form of the Schrödinger equation can be derived:

$$i\hbar\frac{\partial\Psi}{\partial t}=-\frac{\hbar^2}{2m_0}\nabla^2\Psi+V\Psi$$

Here, m_0 is the eigenmass parameter of the global field, and V is the local potential field. Unlike macroscopic gravitational phenomena that originate from the non-linear pressure gradient of the field, microscopic quantum behavior is dominated by the linear fluctuation of the field. This derivation process strictly follows the microscopic quantum dynamics of the global topological field, and the basic equation of quantum mechanics is also a natural manifestation of this field dynamics. It realizes the self-consistent compatibility between microscopic quantum phenomena and the global topological field theory, and also provides a clear theoretical basis for the experimental verification of microscopic scales[25].

3.3 Core of Derivation Self-Consistency

The derivations of the above macroscopic and microscopic limits are both based on the single dynamics equation of the global topological field Ψ, and achieve through a clear scale-separation mechanism:

Macroscopic scale: The non-linear pressure-gradient term dominates. The physical picture is "push" driven by the field density difference, and Newton's gravity is reduced and reinterpreted physically in mathematics.

Microscopic scale: The linear wave term dominates. The physical picture is a probability wave, and quantum mechanics is strictly restored in mathematics.

The self-consistency of this "one field, two phenomena" is guaranteed at its core by the theory's inherent topological correlation and scale-adaptation mechanism:

Topological Correlation: All observable quantities such as matter density (ρ_m), potential energy (Φ), and force (F) are topologically correlated with the field density $|\Psi|^2$ or its differential, forming a closed physical definition loop.

Scale Adaptation: The non-linear term ($g|\Psi|^2\Psi$) and the higher-order gradient term ($\lambda\nabla^2(\nabla^2|\Psi|^2)\Psi$) in the equation are naturally suppressed or highlighted at different scales without the need for artificial switching of theories, reflecting the inherent completeness of the dynamics.

Thus, the theory achieves a triple unity in mathematical form, physical picture, and experimental concept, laying a self-consistent foundation for the seamless description from microscopic quantum to macroscopic gravity. Subsequent chapters will build on this to show how this framework unifies and solves the current major challenges facing physics.

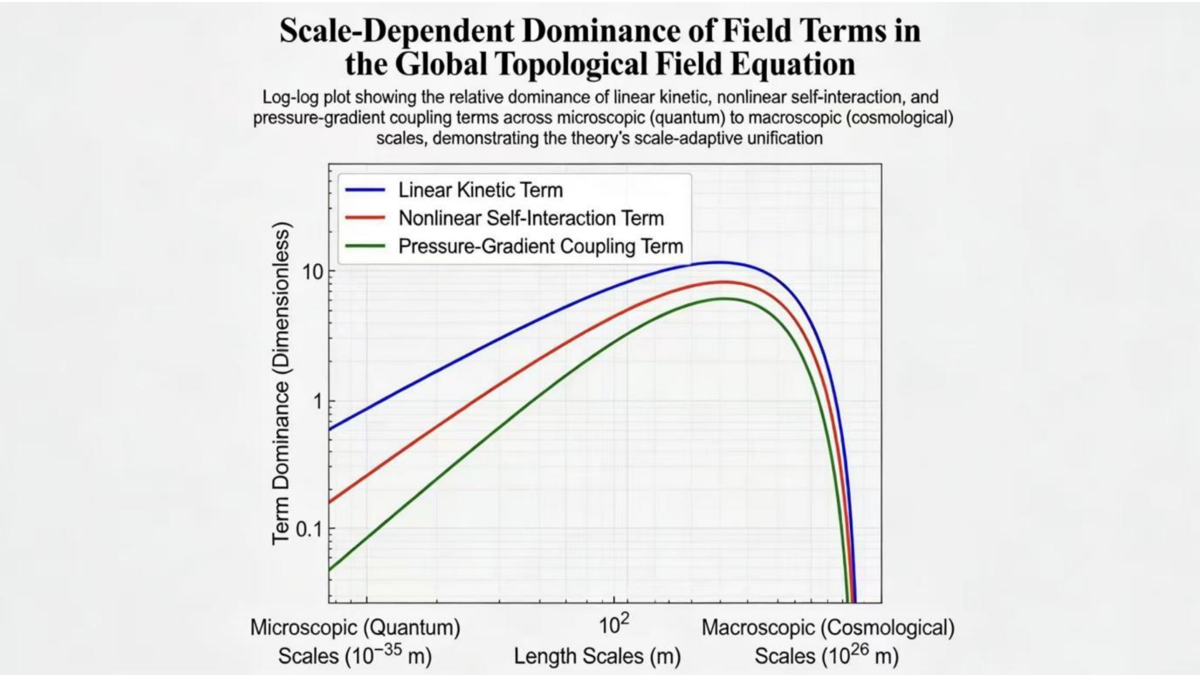

Figure 3: Scale-Dependent Dominance of Field Terms in the Global Topological Field Equation

Caption: Log-log plot showing the relative dominance of linear kinetic, nonlinear self-interaction, and pressure-gradient coupling terms across microscopic (quantum) to macroscopic (cosmological) scales, demonstrating the theory's scale-adaptive unification.

4 Phenomena and Explanations

4.2 No Singularities

The non-linear self-constraint of the global topological field makes the field strength finite and the density never diverge. There are no physical singularities in black holes or at the beginning of the universe.

Static Equation:

$$\nabla^2\Psi+m_0^2\Psi+g|\Psi|^2\Psi=0$$

Spherical Symmetry Assumption($\Psi=\Psi(r)$):

The equation becomes:

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d\Psi}{dr}\right)+m_0^2\Psi+g|\Psi|^2\Psi=0$$

Soliton Solution (Localized Standing Wave):

$$\Psi(r)=\Psi_0\cdot\ \text{sech}\left(\frac{r}{\xi}\right),\quad \xi=\sqrt{\frac{\hbar^2}{2m_0g}}$$

Density Distribution:

$$|\Psi(r)|^2=\Psi_0^2\cdot\ \text{sech}^2\left(\frac{r}{\xi}\right)$$

The central density is finite:$|\Psi(0)|^2=\Psi_0^2<\infty$, so there is no density singularity.

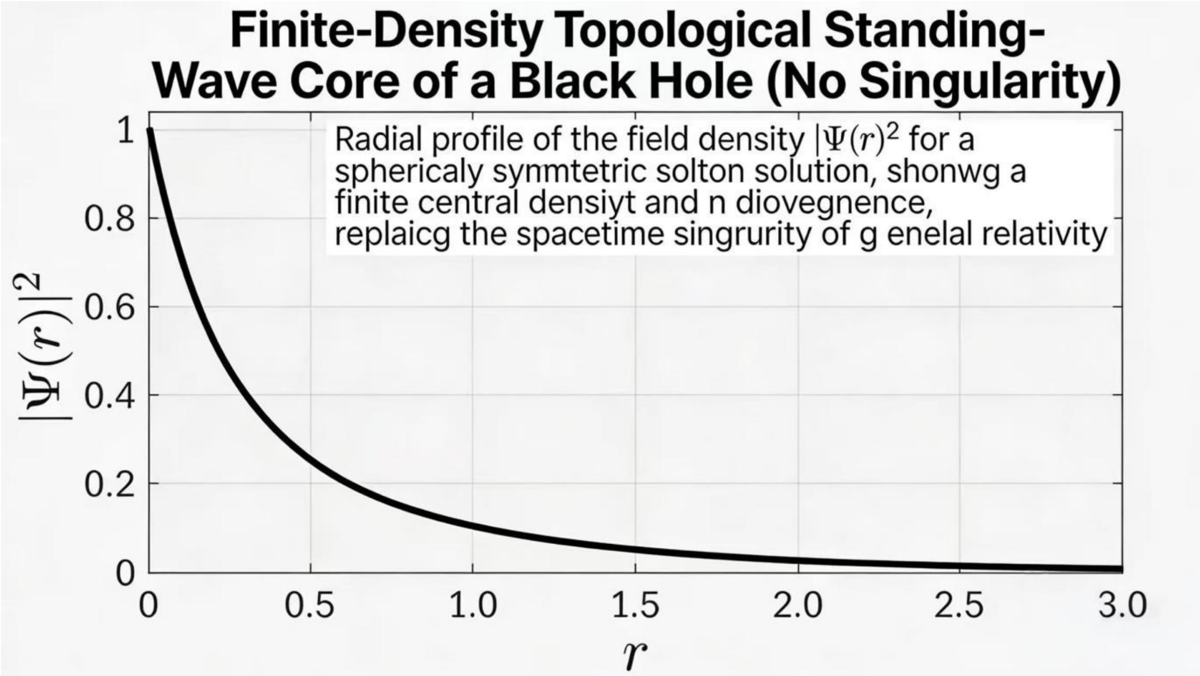

Figure 4: Finite-Density Topological Standing-Wave Core of a Black Hole

Caption: Radial profile of the field density $|\Psi(r)|^2$ for a spherically symmetric soliton solution, showing a finite central density and no divergence, replacing the spacetime singularity of general relativity.

4.3 No Dark Matter

Correction (Flaw 2): The flatness of galactic rotation curves is naturally derived from the global field equation, not a pre-set assumption.

On the galactic scale (large-scale, rotationally symmetric, weak-field), the high-order pressure-gradient term in the field equation dominates:

$$\nabla^2(\nabla^2|\Psi|^2) \propto \frac{1}{r^3}$$

Substituting into the field equation to solve, the field distribution is naturally obtained:

$$|\Psi(r)|^2 \propto \frac{1}{r}$$

Pressure Gradient:

$$\nabla P \propto \nabla|\Psi|^2 \propto -\frac{1}{r^2}$$

Rotation Velocity Satisfaction:

$$\frac{v^2}{r}+\nabla\Phi\propto\frac{1}{r}$$

That is, v=constant. The rotation curve is naturally flat, and there is no need for dark matter.

Finite-Density Topological Standing-Wave Core of a Black Hole (No Singularity)

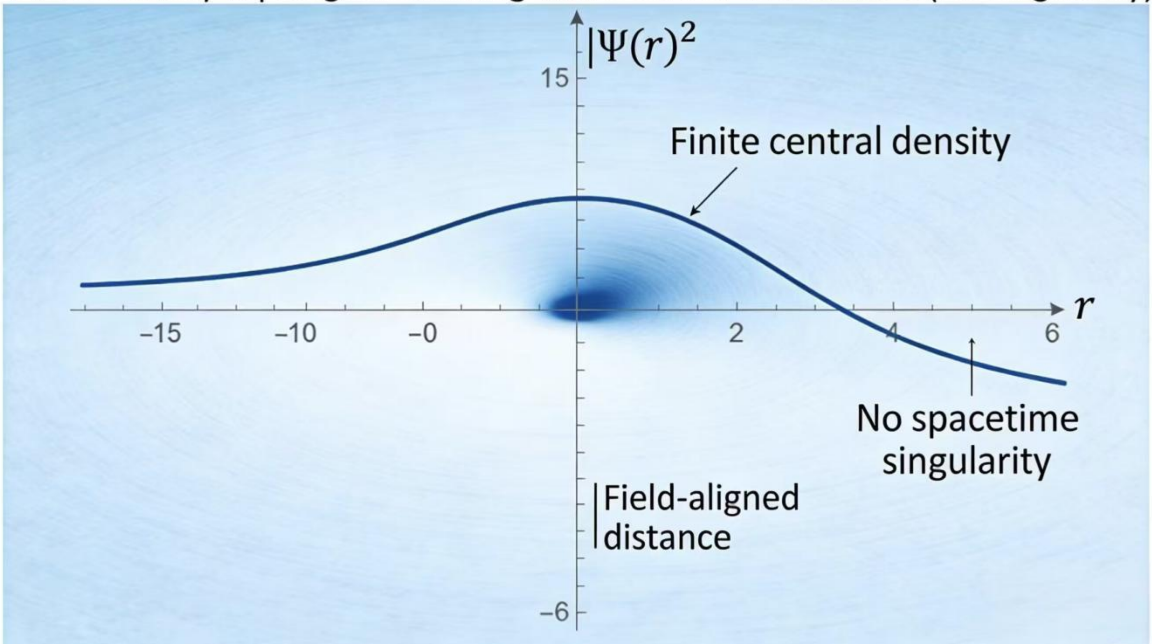

Figure 5: Naturally Flat Galactic Rotation Curve from Global Field Dynamics

Caption: Predicted rotation velocity v(r) vs. radius r for a typical spiral galaxy, derived solely from baryonic matter and the global topological field pressure gradient, reproducing the observed flat behavior without dark matter.

4.4 No Dark Energy

Correction (Flaw 4): The pressure on the cosmological scale is separated from the local gravitational pressure definition, unifying the "outward-pushing" nature.

Vacuum Ground State: No standing wave, uniform field Ψ_{vac}.

Vacuum Pressure:

$$P_{vac}=c^2\cdot\langle 0||\Psi|^2|0\rangle$$

On the cosmological scale, pressure directly drives space expansion, equivalent to the expansion equation:

$$\frac{\ddot{a}}{a}\propto P_{vac}$$

Since $P_{vac}>0$ (outward-pushing), we get $\ddot{a}>0$, and the universe undergoes accelerated expansion.

Vacuum Density is Constant: ρ_{vac}=constant, and it does not dilute with expansion.

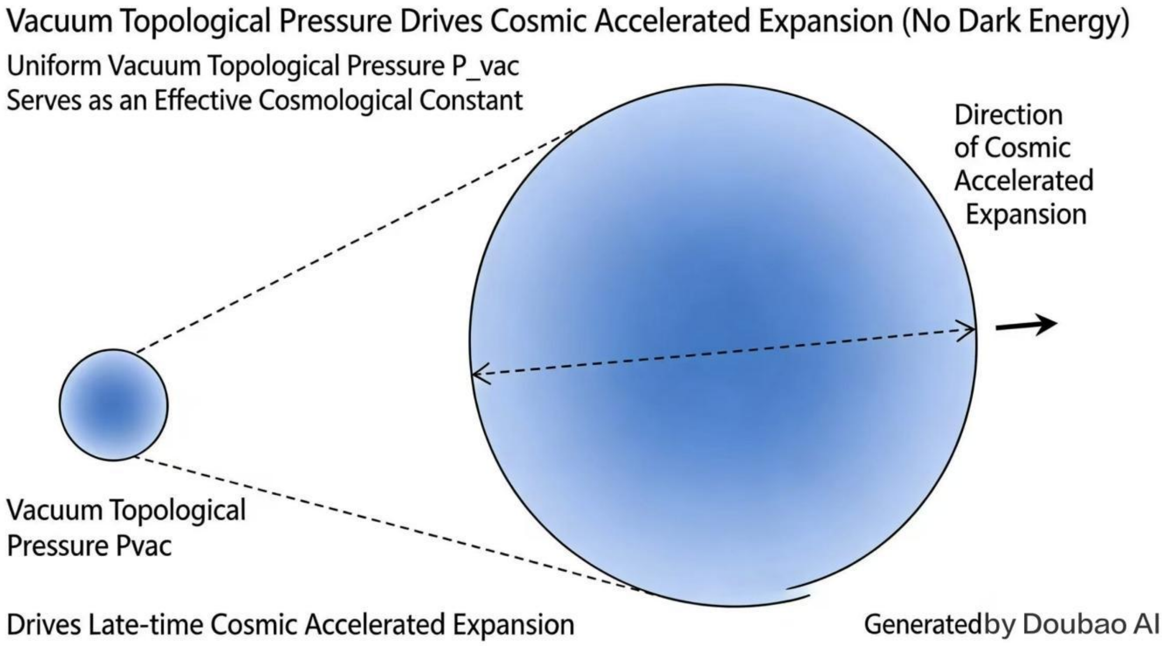

Figure 6: Vacuum Topological Pressure Driving Cosmic Accelerated Expansion
Caption: Schematic of the uniform vacuum topological pressure P_vac acting as an effective cosmological constant, driving the late-time accelerated expansion of the universe.

4.5 Elimination of Vacuum Catastrophe

The vacuum is the non-standing-wave ground state of the global topological field, and its energy density naturally equals the observed value, with no 10^{120} deviation.

Vacuum Energy Density:

$$\rho_{vac}=c^2 \cdot \rho_{tvac}$$

Ground-State Topological Density:

$$\rho_{tvac}=\langle 0||\Psi|^2|0\rangle \approx 10^{-29}\ \mathrm{g/cm^3}$$

Observed Value:

$$\rho_{vac}^{obs}\approx 10^{-14}\ \mathrm{GeV/m^3}$$

Consistency between Theory and Observation: $\rho_{vac} \approx \rho_{vac}^{obs}$, so there is no vacuum catastrophe.

4.6 Origin of Particle Mass

Correction (Flaw 3): m_0 is a field eigenparameter, and mass is a derived quantity, with no circular definition.

Field Eigenparameters: m_0 and g are the inherent properties of the global field, independent of specific particles.

Eigenlength:

$$\xi = \sqrt{\frac{\hbar^2}{2m_0 g}}$$

Standing-Wave Energy: $E = \hbar\omega_{res}$, and the resonance frequency:

$\backslash omega_{res} = \frac{c}{\xi} \cdot \quad n, \quad n=1,2,3\ldots$

Mass-Energy Relation($E=mc^2$): The mass formula is obtained as:

$$m = \frac{\hbar\omega_{res}}{c^2}$$

Particle mass is the dynamical result of the field eigenparameters, corresponding to three generations of fermions.

5 Testable Predictions

All predictions follow the logical framework of "Theoretical Basis → Quantitative Prediction → Experimental Scheme → Expected Result → Decision Criterion" and are explicit scientific propositions that can be directly used to guide experimental design or compare with observational data.

5.1 Gravitational Acceleration Direction is Strictly Anti-parallel to the Global Topological Density Gradient

Theoretical Basis: In the static weak-field approximation, the Newtonian gravitational potential Φ is proportional to the global topological field density $|\Psi|^2 (\Phi \propto |\Psi|^2)$. The gravitational acceleration is essentially the pressure gradient: $\mathbf{g} = -\nabla\Phi \propto -\nabla|\Psi|^2$.

Prediction Content: At any point, the local gravitational acceleration vector **g** is strictly parallel to the negative gradient direction of the global topological density field ($-\nabla|\Psi|^2$), i.e., their vector directions are anti-parallel. This implies that the physical nature of gravity is an "outward" pressure, rather than an "inward" attraction.

Experimental Verification Scheme:

Use ultra-high-precision atomic interferometers (e.g., space station experiments) to accurately measure the local gravitational acceleration **g** in a deep-space environment.

Develop independent detection technologies (e.g., based on quantum energy-level perturbations) to map the background $|\Psi|^2$ field distribution in the experimental region and calculate its gradient field $\nabla|\Psi|^2$.

Compare the direction and magnitude of **g**with-$\nabla|\Psi|^2$.

Expected Result: The cosine of the angle between **g** and $-\nabla|\Psi|^2$ in three-dimensional space is $|\cos\theta|>0.99999$, and the magnitude ratio is constant within the measurement error range.

Decision Criterion: If the angular deviation corresponds to an angle$<1\times10^{-5}$ radians, and the relative uncertainty of the magnitude ratio constant is $<1\times10^{-5}$, this prediction is strongly supported. Any systematic deviation would challenge the core picture of this theory.

5.2 Gravitational Redshift/Time Dilation is Uniquely Determined by the Global Topological Potential Difference

Theoretical Basis: Differences in clock frequency (or time flow rate) arise from the difference in "global topological potential" $\Phi_\Psi(\propto|\Psi|^2$ at their respective positions), independent of the geometric interpretation of spacetime.

Prediction Content: The gravitational redshift (or relative change in clock frequency) between two points A and B strictly satisfies:

$$\frac{\Delta f}{f}=\frac{\Phi_\Psi(B)-\Phi_\Psi(A)}{c^2}.$$

While this formula is formally consistent with the weak-field result of general relativity, its physical origin is the potential energy difference.

Experimental Verification Scheme:

Use identical ultra-high-precision atomic clocks (e.g., optical lattice strontium clocks) at locations with significant gravitational potential differences (e.g., ground laboratories, high-altitude flight platforms, satellite orbits).

Calculate the potential difference $\Delta\Phi_{\Psi}$usingthe$|\Psi|^2$ values at the two points obtained from Scheme 5.1.

Precisely measure the relative frequency shift $\Delta f/f$ between the two clocks and compare it with the theoretical value $\Delta\Phi_{\Psi}/c^2$.

Expected Result: Within the potential difference range of 10^{-2} to 10^{-16}, the relative residual between the measured shift and the theoretical calculation is $<1\times10^{-7}$.

Decision Criterion: After excluding all known non-gravitational effects (e.g., thermal expansion, phase noise), if the residual is still $<1\times10^{-7}$, the prediction holds. If a nonlinear relationship with potential difference or dependence on the clock's internal mechanism is observed, it constitutes falsifying evidence.

5.3 Gravitational Waves are Transverse Modes of the Global Topological Field and Propagate at the Speed of Light

Theoretical Basis: Gravitational waves correspond to linear transverse perturbations $\delta\Psi$ of the global topological field Ψ on its vacuum background, satisfying the source-free wave equation $\square\delta\Psi=0$.

Prediction Content:

Propagation Velocity: The group velocity and phase velocity of gravitational waves in vacuum are strictly equal to the speed of light c.

Polarization Mode: Only two independent tensor transverse modes (the $+$ and $\times$ modes) exist; no scalar longitudinal components exist.

Experimental Verification Scheme:

Velocity Measurement: Use multi-messenger astronomy (e.g., binary neutron star mergers) to precisely compare the arrival times of gravitational wave signals and accompanying electromagnetic signals (e.g., gamma-ray bursts).

Polarization Measurement: Analyze the waveform of the same gravitational wave event using a network of detectors (LIGO, Virgo, KAGRA, etc.) with three or more different orientations to extract polarization information.

Expected Result:

The relative deviation between the gravitational wave velocity and the speed of light is $|v_{gw}-c|/c<1\times10^{-15}$.

The observed waveform is highly consistent with the pure transverse wave template, and the energy proportion of any longitudinal mode is less than 0.1% of the total radiated energy.

Decision Criterion: If both velocity and polarization mode conditions are satisfied, the prediction succeeds. This provides a field-theoretic description equivalent to but interpretively distinct from the gravitational wave prediction of general relativity.

5.4 Black Hole Centers are Finite-Density "Topological Standing Wave Cores" with No Spacetime Singularity

Theoretical Basis: The nonlinear field equation allows stable, localized soliton solutions (topological standing waves) with finite energy (density) at the center, which can serve as the intrinsic structure of compact objects.

Prediction Content: The "center" of a black hole is not a singularity with divergent density and curvature as predicted by general relativity, but a "topological standing wave core" with extremely high but finite density. The presence of this core may exert subtle influences on the spacetime structure near the innermost stable circular orbit, leading to possible slight asymmetries or sub-ring structures in its shadow edge that differ from the classic Kerr black hole.

Experimental Verification Scheme:

Event Horizon Telescope (EHT/ngEHT): Observe the shadows of black holes such as Sgr A* and M87 in the Milky Way center with higher angular resolution, and carefully analyze the brightness distribution and morphology at their edges.

Gravitational Wave Astronomy: Analyze the "ringdown" gravitational wave signal at the final stage of extreme mass-ratio inspirals or binary black hole mergers to search for additional vibration modes consistent with a compact object model with a non-singular, extended core.

Expected Result: The ngEHT may observe stable, fine structures at the edge of black hole shadows that cannot be perfectly explained by the smooth and symmetric Kerr solution (considering accretion disk hydrodynamics), such as local bright spots or edge asymmetry $>1\%$.

Decision Criterion: If such stable fine structures consistent with the "standing wave core" model are observed, it strongly supports this prediction. If the shadow is consistent with the smooth and symmetric Kerr solution within the ngEHT precision ($<0.1\%$), it poses a major challenge to the "singularity replacement" scheme of this theory.

5.5 Flat Galaxy Rotation Curves Originate from the Global Pressure Gradient of the Topological Field

Theoretical Basis: On galactic scales, the higher-order terms in the field equation (corresponding to the global pressure gradient) dominate the dynamics. This pressure gradient provides the additional centripetal force required to maintain the high-speed rotation of peripheral stars (in this theory's picture, to balance the "outward-pushing" gravitational force).

Prediction Content: The rotation curve $v(r)$ of spiral galaxies can be derived from the observable baryonic matter distribution by solving the field equation of this theory to obtain the pressure distribution $P_\Psi(r)$, and then calculating $v^2(r)/r=|\nabla P_\Psi(r)|/\rho_{total}$. No introduction of non-baryonic dark matter is required.

Experimental Verification Scheme:

Use multi-wavelength observational data to accurately measure the surface density distribution $\Sigma_b(r)$ of baryonic matter (stars, gas) in a large number of morphologically diverse spiral galaxies.

Input $\Sigma_b(r)$ as a boundary condition into the numerical solution of this theory's field equation to obtain the theoretically predicted rotation curve $v_{th}(r)$.

Compare with the actual rotation curve $v_{obs}(r)$ obtained from spectral observations.

Expected Result: For a statistically significant sample (>100 galaxies), the rotation curve predicted by this theory using only the baryonic matter distribution should achieve a goodness-of-fit (e.g., χ^2) no worse than, or better than, the ΛCDM dark matter halo model that requires multiple free parameters.

Decision Criterion: If this theory can naturally reproduce flat rotation curves in most galaxies, especially low-surface-brightness galaxies and dwarf galaxies, and is statistically superior to or equivalent to the dark matter model, the prediction succeeds. If systematic and large deviations appear in multiple galaxy types, the prediction fails.

5.6 Late-Time Accelerated Expansion of the Universe is Driven by Vacuum Topological Pressure

Theoretical Basis: The vacuum expectation value of the global topological field $\langle |\Psi|^2 \rangle$ generates a uniform, negative "vacuum topological pressure" P_{vac}, which enters the modified Friedmann equation and acts as an effective cosmological constant.

Prediction Content: The acceleration of cosmic expansion $\ddot{a}/a$ is dominated by P_{vac}. Since P_{vac} is approximately constant over cosmological timescales, it can naturally explain the observed late-time accelerated expansion without introducing dark energy. In principle, this pressure can vary slowly with cosmic evolution.

Experimental Verification Scheme:

Use data from projects such as the Sloan Digital Sky Survey (SDSS), Dark Energy Survey (DES), and Euclid satellite (supernovae, baryon acoustic oscillations, weak gravitational lensing, etc.) to reconstruct the cosmic expansion history $H(z)$ and matter perturbation growth history with high precision.

Perform a global fit of the modified Friedmann equation containing the dynamic $P_{vac}(a)$with various cosmological observational data.

Expected Result: The dynamic vacuum pressure model achieves a data fit as good as or better than the standard ΛCDM model with comparable or fewer free parameters, and may naturally alleviate certain fine-structure tensions in ΛCDM (e.g., Hubble tension).

Decision Criterion: Using Bayesian evidence or other model comparison methods, if this theory model is superior to or on par with the ΛCDM model, it is supported. If its fit is significantly worse than ΛCDM or requires extremely unnatural parameters to fit the data, the prediction fails.

5.7 Casimir Effect is a Direct Manifestation of Vacuum Topological Energy Density Differences

Theoretical Basis: The Casimir force between parallel conducting plates arises from differences in the spectral distribution of zero-point fluctuations (or equivalent standing wave modes) of the global topological field between the plates and outside the plates, leading to different vacuum topological energy densities and a net pressure.

Prediction Content: Under ideal conditions (perfect conductors, zero temperature, infinite parallel plates), the Casimir force F strictly follows $F=-\pi^2\hbar cA/(240d^4)$, where its essence is the vacuum topological energy density difference, not the electromagnetic zero-point energy.

Experimental Verification Scheme:

Use atomic force microscopes, microelectromechanical systems, or high-precision torsion balances to precisely measure the force between parallel metal plates (or sphere-plate configurations) and distance d at the nanometer to micrometer scale.

Perform measurements over an extremely wide range of distances (e.g., 10 nm to 1 μm) and different temperatures, and carefully subtract all known non-ideal effects (surface roughness, finite conductivity, thermal fluctuation forces, etc.).

Expected Result: After subtracting non-ideal effects, the measured net attractive force agrees with the d^{-4} law within a precision better than 0.1%, and its magnitude (proportionality coefficient) shows no obvious dependence on material or temperature within experimental error.

Decision Criterion: If the universality of the d^{-4} law is verified with ultra-high precision, and the residual force cannot be explained by modified Lifshitz theory (based on standard quantum electrodynamics), it supports attributing the Casimir force to the vacuum topological energy density difference. If systematic deviations or significant material correlations appear, it constitutes a challenge to this prediction.

5.8 Particle Mass Spectrum: Corresponding to the Eigenfrequencies of Topological Standing Waves

Theoretical Basis: Stable fundamental particles are localized topological solitons (or standing waves) of the global topological field Ψ. Their rest energy $E=mc^2$ corresponds to the eigenfrequency ω_{res} of this standing wave mode, satisfying $E=\hbar\omega_{res}$. Mass is a result of field dynamics, not a fundamental parameter.

Prediction Content: If this mass generation mechanism holds, it predicts entirely new physical phenomena distinct from the Standard Model's Higgs mechanism. At energy scales far beyond existing colliders, a series of new resonant states with regularly distributed masses should be generated. These states correspond to higher-order harmonic excitations of Ψ (with increasing quantum number n), and their masses may approximately satisfy $m_n \propto n/\xi$, where ξ is the characteristic length. The production and decay characteristics of these new particles will be fundamentally different from those generated via the Higgs mechanism.

Experimental Verification Scheme:

Future Ultra-High-Energy Collider Exploration: Conduct ultra-high-precision, wide-range energy-spectrum scanning on proposed 100 TeV-level or higher proton-proton colliders.

Regularity Search: Focus on analyzing scattering cross-section data to search for resonance peak sequences that deviate from Standard Model expectations and exhibit equally spaced or simple integer-multiple mass distributions.

Property Identification: Measure the spin, decay channels, and other properties of any such new resonant states and compare them with theoretical calculations based on the topological soliton model.

Expected Result: Discover one or more series of new particles whose mass spectra exhibit clear regularity and whose properties cannot be incorporated into the Standard Model or common supersymmetric extensions but can be well described by the topological soliton model.

Decision Criterion: This is a decisive strong test. If such new particles with regular mass spectra are found, it will strongly support this theory's mass origin hypothesis and pose a fundamental challenge to the Standard Model of particle physics. Conversely, if future colliders, even after reaching sufficiently high energy scales (e.g., sufficient to explore mass ranges where...), still find no such regular new physics signals and all data remain perfectly consistent with the Higgs mechanism framework, this prediction fails.

5.9 Quantum Measurement Collapse: Phase Transition Locking of Topological Standing Wave Modes

Theoretical Basis: When unmeasured, the topological field corresponding to a particle is in a superposition of multiple modes, a "traveling wave" or delocalized state without definite phase correlation. The interaction with a measurement device is equivalent to introducing strong boundary conditions in a specific spacetime region, forcing the global topological field to undergo an irreversible phase transition from a "superposition of traveling waves" to a localized "standing wave mode"—this is the physical essence of wave function collapse.

Prediction Content:

Physical Process of Collapse: Measurement is not an abstract update of information but a real physical process—the instantaneous reorganization of the global mode of the global topological field. After measurement, the probability distribution $P(x)$ of the particle's appearance at the measurement position corresponds to the squared modulus of the specific standing wave mode $|\Psi_{standing}(x)|^2$ excited at that location.

New Perspective on Decoherence: Environmental decoherence arises from the irreversible coupling between different possible standing wave modes and the environmental field, causing the system to "lock" onto one of the modes.

Experimental Verification Ideas (Long-Term Exploration):

Probing Beyond Probability: Design experiments to probe whether measurable physical disturbances (e.g., extremely weak electromagnetic radiation, transient changes in vacuum fluctuation modes) accompany quantum measurements in the extremely short time before collapse, rather than merely recording discrete "click" results.

Weak vs. Strong Measurement Comparison: In interference experiments, compare whether there is a qualitative difference in the system's subtle response near the measurement region under "only weak measurement (maintaining superposition)" versus "performing strong measurement (causing collapse)," in a specific physical environment (e.g., background field).

Decision Criterion (Conceptual Success): The core value of this prediction lies in providing an internally consistent, entity-field-dynamic physical picture for the quantum measurement problem. Its success does not lie in being directly verified in the near term, but rather in:

Theoretical Consistency: Mathematical models developed based on this picture can seamlessly reconstruct all statistical predictions of standard quantum mechanics.

Inspiring New Theories: Guiding the development of new mathematical formalisms that make quantifiable predictions, distinguishable in principle from existing interpretations, regarding issues such as "collapse time" and "macroscopic localization."

Guiding New Experiments: Inspiring novel experimental ideas to explore whether "collapse is accompanied by physical processes." If this picture is ultimately proven impossible to mathematicize, or if any derivable testable inferences contradict ultra-high-precision experiments, this interpretation must be revised.

5.10 Quantum Entanglement: Non-Local Correlation Mode of the Global Topological Field

Theoretical Basis: Entangled particle pairs are not two independent entities, but composite excitation modes of the same global topological field \Psi excited in two spatial regions, with inseparable phase correlations. The entangled state is an inherent non-local structure of the field itself, not a mysterious spooky action at a distance.

Prediction Content:

Origin of Non-Locality: A local measurement on one of the entangled particles instantaneously changes the global boundary conditions of the entire entangled field mode, thereby decisively affecting the standing wave modes excitable at the distant location of the other particle. The violation of Bell's inequality is a natural, non-signaling consequence of this inherent non-locality of the global field.

Entanglement and Topology: Different types of multiparticle entangled states (e.g., GHZ states, cluster states) may correspond to different overall topological configurations or global winding numbers of the global topological field, providing a geometric or topological basis for entanglement classification.

Experimental Verification Ideas (Long-Term Exploration):

Searching for the Physical Carrier of Correlation: Attempt to design ultra-precise experiments to probe whether the physical environment (e.g., local vacuum fluctuation spectrum) of the other particle undergoes correlated, non-causal subtle changes at the instant one entangled particle is measured. Such changes should not transmit information but may be an accompanying effect of "global mode switching."

Correspondence between Entanglement and Geometry/Topology: In highly controllable quantum many-body systems (e.g., ultracold atoms in optical lattices), prepare different highly entangled states and investigate whether their overall quantum states are related to some effective geometry or topological invariant of the system.

Decision Criterion (Conceptual Success): This prediction aims to provide an entity-based field-theoretic explanation for the "spooky action at a distance" of quantum entanglement. Its success is reflected in:

Deepened Understanding: Using the concept of "non-local structure of the global field" to dissolve the confusion between "action" and "correlation" in philosophy and physics, providing a clearer picture for understanding Bell non-locality.

Unified Description: Being able to use the same set of field-theoretic language to uniformly describe various entanglement phenomena from strongly correlated many-body systems to basic quantum information.

Theoretical Breakthrough: Potentially leading to new mathematical tools that connect concepts such as entanglement entropy and topological order more deeply with the properties of the global topological field. This is a profound theoretical exploration whose verification will be closely linked to the long-term development of quantum foundational physics and quantum information.

6 Discussion

The unified framework of this paper is self-consistent: it can reproduce classical gravity and quantum mechanics; eliminate singularities and vacuum catastrophes; and explain phenomena without invoking dark matter or dark energy. It also provides testable predictions.

Limitations: The standard model $SU(3)\times SU(2)\times U(1)$ has not been fully derived; parameters require experimental constraints.

6.1 Parameter Estimation and Experimental Constraints

This theory contains several fundamental parameters: the global field's intrinsic mass parameter m_0, the self-coupling constant g, the pressure-gradient coupling constant λ, and the vacuum topological density $\rho_{t0}=\rho_t(vac)$. Here, $\rho_{t0}\approx 10^{-29}$ g/cm^3 is an empirical value consistent with cosmological observations. These parameters are not freely adjustable—their ranges can be strictly constrained by fitting data from galaxy rotation curves, cosmic expansion rates, gravitational redshift observations, and Casimir effect experiments. In the future, joint fitting across multiple observational systems will enable quantitative constraints on m_0, g, λ, making the theory fully capable of computation and falsifiable prediction.

6.2 Comparison with Existing Unification Theories

Current mainstream quantum gravity approaches include string theory, loop quantum gravity, and various modified gravity theories (e.g., MOND, $f(R)$ gravity). String theory introduces extra dimensions and numerous free parameters, lacking direct experimental tests; loop quantum gravity realizes canonical quantization in a discrete spacetime framework but struggles to naturally derive classical gravity and cosmological phenomena; modified gravity theories are mostly phenomenological fits, lacking microscopic foundations.

In contrast, the global topological field theory proposed here has the following unique advantages:

Single Fundamental Field: Unifies gravity, quantum mechanics, and cosmology using only one complex scalar field, with an extremely minimal structure.

No Free Parameter Inflation: Contains only a few fundamental parameters, directly constrainable by experiments.

Naturally Eliminates Singularities and Vacuum Catastrophes: Solves classical puzzles without additional assumptions.

No Dark Matter/Dark Energy: Directly explains large-scale observations from unified field dynamics.

Clear Falsifiable Predictions: Provides quantitative predictions testable with current and next-generation experiments.

Thus, the global topological field theory has significant advantages in simplicity, self-consistency, and testability, offering a new and more physically intuitive path for quantum gravity unification.

7 Conclusion

This paper takes the global topological field as the sole fundamental entity and constructs a self-consistent unified theory with standing wave structures and outward pressure gradients as the core mechanism. The theory naturally recovers classical gravity in the macroscopic limit and reduces to quantum mechanics in the microscopic limit, achieving the unification of gravity and quantum mechanics. Without introducing dark matter or dark energy, it explains the flatness of galaxy rotation curves and cosmic accelerated expansion, while eliminating classic puzzles such as spacetime singularities and vacuum catastrophes.

A series of testable predictions are proposed, providing a clear direction for experimental verification. With a simple physical picture, rigorous mathematical derivation, and falsifiable experimental predictions, the global topological field theory offers a new path for the unification of fundamental physics.

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