Scale-Dependent Geometrodynamics: Conceptual Foundations and Axiomatic Structure (Abridged Version)

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Abstract

This paper presents a novel theoretical paradigm — Scale-Dependent Geometrodynamics (SDG), offering a conceptually different approach to understanding the fundamental structure of reality. Unlike traditional approaches, SDG views the observable three-dimensional world as a projection of more fundamental multidimensional structures, with scale-dependent effective dimensionality of space and a three-component structure of time. A key element of the theory is monopolar eversion — a special topological mechanism connecting the limit states of scale-dependent dimensionality and creating a closed self-referential structure of reality. The paper outlines the fundamental axioms of SDG that form its conceptual and logical foundation, and discusses their implications for understanding phenomena such as dark matter, dark energy, quantum entanglement, and the origin of the Universe. The proposed theory opens new perspectives for addressing a number of fundamental problems in modern theoretical physics and offers a conceptual framework for their unified understanding.

Key terms:

Scale-Dependent Geometrodynamics (SDG), **Effective dimensionality of space**, **Monopolar eversion**, **Temporal composite**, **Projection Mechanism**

1 Introduction

Modern theoretical physics faces a number of fundamental problems that do not find satisfactory solutions within existing models. Despite the significant successes of the Standard Model of elementary particles and General Relativity, fundamental questions remain unresolved, such as the incompatibility between quantum mechanics and gravity, the nature of dark matter and dark energy, the origin of baryon asymmetry, and the problem of scale hierarchy.

The traditional approach to solving these problems often involves supplementing existing theories with new entities: additional particles, fields, or dimensions, but without a fundamental revision of basic principles. **Scale-Dependent Geometrodynamics (SDG)**proposes a fundamentally different approach — a revision of the fundamental understanding of the structure of reality, considering it as a multi-level system with scale-dependent characteristics.

The key idea of SDG is as follows: the three-dimensional world we observe is a projection of more fundamental multidimensional structures. The **Effective dimensionality of space**$D_{eff}(\mu)$ is not a constant but depends on the scale level at which a physical system is considered (parameter μ). This leads to a spectrum of physical regimes, each characterized by its specific properties. Various physical laws and phenomena at different scales are manifestations of more fundamental patterns projected into different dimensional regimes.

Another fundamental aspect of SDG is the concept of a three-component structure of time (**Temporal composite**), which includes components such as **Chronoangle**(parameter of temporal flow orientation), **Chronofrequency**(parameter of process rate), and **Chronotopology**(structure of cause-effect relationships), which significantly expands our understanding of the temporal aspects of reality.

A special role in the theory belongs to a specific topological mechanism called **Monopolar eversion**, which connects the limit states of scale-dependent dimensionality and creates a closed self-referential structure of reality (**Uroboros**). It is this mechanism that ensures the integrity of the theory and the possibility of explaining fundamental physical phenomena, from quantum effects to cosmological scales, within a unified conceptual approach.

1.1 Necessity of a New Conceptual Approach

1.1.1 Fundamental Limitations of Existing Theoretical Approaches

Despite the significant achievements of modern theoretical physics, existing approaches face fundamental limitations:

1. **Absence of a unified foundation for quantum theory and gravity.** After almost a century of intensive research, a generally accepted theory of quantum gravity has not been formulated. The main candidates — string theory and loop quantum gravity — face fundamental mathematical and conceptual difficulties, as well as a lack of experimentally verifiable predictions. The key problem lies in fundamentally different approaches to spacetime in these theories: in quantum mechanics, spacetime is a fixed background for quantum processes, whereas in general relativity it is a dynamic entity.

2. **The problem of ad hoc hypotheses in cosmology.** The modern cosmological model ΛCDM requires the introduction of dark matter and dark energy, which constitute about 95% of the Universe's content, but the nature of which remains unknown despite decades of searching.

3. **The problem of quantum mechanics interpretation.** Despite unprecedented predictive accuracy, quantum mechanics remains conceptually problematic, with multiple competing interpretations but no generally accepted solution to the measurement problem and nonlocality.

4. **Scale hierarchy and unification of interactions.** Existing approaches to grand unified theory face the problem of scale hierarchy and require fine-tuning of parameters, indicating the absence of more fundamental principles determining these parameters.

1.1.2 Methodological Limitations of Existing Paradigms

Beyond specific physical problems, existing theoretical paradigms have certain methodological limitations:

1. **Fixed dimension of spacetime.** Traditional approaches, including string theory and standard cosmological models, either fix the dimension of spacetime (usually 3+1 or 10/11 dimensions in string theory) or allow compactified extra dimensions, but do not consider the possibility of scale-dependent effective dimensionality.

2. **One-dimensional concept of time.** Almost all existing physical theories are based on a one-dimensional concept of time, which limits the possibilities for explaining certain quantum phenomena and cosmological anomalies.

3. **Separation of informational and physical aspects.** Although the informational approach is gaining increasing importance in quantum physics and thermodynamics, existing theories do not consider information as an ontologically primary category, which limits the possibilities for integrating informational and physical aspects of reality.

Historical experience shows that solving the most fundamental problems in physics often requires not just an extension of existing theories, but a revision of basic conceptual premises. Examples include the transition from Newton's absolute space and time to Einstein's four-dimensional spacetime, or the transition from classical determinism to the quantum probabilistic paradigm.
Currently, physics is in a situation where a significant number of anomalies and unsolved problems have accumulated, which are difficult to resolve within existing paradigms without introducing numerous ad hoc hypotheses. This indicates the need for a more radical revision of fundamental premises.
Scale-Dependent Geometrodynamics proposes precisely such a radical revision, introducing concepts of scale-dependent dimensionality, three-component time, and informational primacy. This allows approaching fundamental problems from principally new positions, opening possibilities for a unified explanation of phenomena that, within existing paradigms, require the introduction of disparate hypotheses and entities.

2 Terminological Connection to Modern Physics

2.1 Historical Development of the Geometrodynamics Concept

The term "geometrodynamics" has a rich history in theoretical physics and is closely linked to the program of geometrization of physics proposed by John Archibald Wheeler. For the correct positioning of Scale-Dependent Geometrodynamics (SDG) in the context of modern physics, it is necessary to establish clear connections with previous concepts and theories.

Definition 1 (Wheeler's Classical Geometrodynamics) *Classical geometrodynamics, developed by John Wheeler in the 1950s-60s, represents an approach to describing gravity and electromagnetism exclusively through the geometry of spacetime. Key aspects include:*

1. *Interpretation of matter as a manifestation of curved spacetime geometry ("matter without matter").*
2. *The concept of "geon" — an electromagnetic or gravitational wave packet held together by its own gravitational attraction.*
3. *The "everything as geometry" program, seeking to express all physical phenomena through geometric structures.*

Scale-Dependent Geometrodynamics develops this program by adding fundamentally new elements:

1. Scale-dependent effective dimensionality of space $D_{eff}(\mu)$.

2. Three-component structure of time $T(\mu) = \{\theta_t(\mu), \omega_t(\mu), \tau_t(\mu)\}$.

3. The monopolar eversion mechanism, providing a closed self-referential structure of reality.

Thus, SDG can be considered as a generalization and development of Wheeler's classical geometrodynamics, expanding its conceptual and mathematical apparatus to address contemporary problems in physics.

Observation 1 (Connection to Other Geometric Approaches) *SDG has meaningful connections with other geometric approaches in theoretical physics:*

1. ***Kaluza-Klein Theory:*** *Unifies gravity and electromagnetism through the introduction of a fifth dimension. SDG generalizes this approach by introducing scale-dependent dimensionality instead of a fixed number of dimensions.*

2. ***Einstein's Geometrization Program:*** *Einstein's pursuit of a unified field theory based on geometric principles. SDG develops this program by adding scale dependence to geometric structures.*

3. ***Penrose's Twistor Theory:*** *Describes spacetime through more fundamental entities — twistors. SDG similarly postulates a more fundamental reality projecting into the observable world.*

2.2 Temporal Composite (Three-Component Time) in the Context of Physical Theories of Time

The concept of three-component time is an original element of SDG, but it has some parallels with existing multi-time formalisms in physics.

Definition 2 (Multi-time Formalisms in Physics) *Several approaches in modern physics use expanded concepts of time:*

1. ***Multi-time formulation of quantum field theory:*** *Introduces separate time parameters for different interacting systems to preserve relativistic invariance.*

2. ***Two-time formulation of Fokker mechanics:*** *Uses two time parameters to describe systems with delayed interactions.*

3. ***Thermal time in thermodynamics:*** *A formalism introducing an additional time coordinate to describe thermodynamic processes.*

The three-component time of SDG differs from these approaches in its fundamental nature and structure:

Theorem 1 (Uniqueness of SDG's Three-Component Time) *SDG's three-component time, including chronoangle θ_t, chronofrequency ω_t, and chronotopology τ_t, has the following unique features:*

1. *Time components have a clear geometric interpretation in the context of multidimensional space.*

2. *Scale dependence of time components $T(\mu) = \{\theta_t(\mu), \omega_t(\mu), \tau_t(\mu)\}$ naturally explains different regimes of temporal processes at various scales.*

3. *Chronotopology τ_t provides a topological basis for explaining quantum correlations and nonlocality.*

4. *All three components form a unified temporal structure, perceived as one-dimensional time at mesoscopic scales.*

2.3 Information Tensor and Its Relation to Modern Informational Physics

The concept of the information tensor in SDG has parallels with some developing directions in modern physics related to the informational approach.

Definition 3 (Information Geometry and Fisher Tensor) *Information geometry is a branch of mathematics studying the differential-geometric structure of probability distribution spaces. The key object is the Fisher tensor, which defines a metric on the space of probability distributions:*

$$g_{ij}^F = \mathbb{E}\left[\frac{\partial \ln p(x|\theta)}{\partial \theta^i}\frac{\partial \ln p(x|\theta)}{\partial \theta^j}\right] \tag{1}$$

where $p(x|\theta)$ is a probability distribution with parameters θ, and $\mathbb{E}$ is the expectation value.

The information tensor of SDG has structural similarity to the Fisher tensor but extends its concept:

Observation 2 (Relationship of SDG Information Tensor to Fisher Tensor)

1. *Both tensors characterize the informational content of a system in geometric terms.*

2. *The Fisher tensor is defined on the space of probability distributions, while the information tensor of SDG is defined on physical spacetime with scale-dependent dimensionality.*

3. *The SDG information tensor includes spatial, temporal, and informational components, which extends the concept of the Fisher tensor.*

4. *The scale dependence of the SDG information tensor has no direct analog in classical information geometry.*

Theorem 2 (Connection to the Informational Approach in Physics) *The information tensor of SDG provides a bridge between the informational approach and the geometric approach in physics:*

1. *In the limit of weak gravitational fields and fixed effective dimensionality, the information tensor is related to the energy-momentum tensor in general relativity.*

2. *In the quantum regime, the information tensor is related to the quantum Fisher tensor and the density matrix of a quantum system.*

3. *In the thermodynamic regime, the information tensor is related to thermodynamic potentials and fluctuations.*

These connections demonstrate that SDG provides a unified information-geometric foundation for various physical regimes.

3 Axiomatic Foundations of SDG

3.1 Fundamental Principle of SDG

Axiom 1: Fundamental Principle of SDG

Reality is multidimensional (multi-level) in nature, with scale-dependent effective dimensionality, mapped onto itself through the action of spacetime projection operators and scale-dependent functions, forming a closed self-referential structure (uroboros) through a special topological mechanism — monopolar eversion. Reality depends on its geometry at each level and scale of observation, on the degree of differentiation of its structure, on its dynamics, and also depends on the degree of activity of processes occurring within these levels (on metric time, which also possesses scale dependence).

This axiom establishes the fundamental multidimensionality and multi-level nature of reality, pointing to key aspects of the theory: scale-dependent dimensionality, the projective nature of observable phenomena, and monopolar eversion as a mechanism ensuring self-closure and integrity of the structure of reality.

3.2 Informational Nature of Reality

Axiom 2: Information as a Primary Category

Information is a fundamental structural differentiation of multidimensional space, forming a network of interacting relational states that project into our three-dimensional world as matter and energy. Information represents an ontologically primary category, preceding matter and energy.

The information tensor $\mathcal{I}^A_B(x,\mu)$ is defined as a characteristic of the local state of structural differentiation at point x at scale μ. The tensor has a generalized structure:

$$\mathcal{I}^A_B(x,\mu) = \begin{pmatrix} \mathcal{I}^{\mathrm{s}}_{\mathrm{s}}(x,\mu) & \mathcal{I}^{\mathrm{s}}_{\mathrm{t}}(x,\mu) & \mathcal{I}^{\mathrm{s}}_{\mathrm{i}}(x,\mu) \\ \mathcal{I}^{\mathrm{t}}_{\mathrm{s}}(x,\mu) & \mathcal{I}^{\mathrm{t}}_{\mathrm{t}}(x,\mu) & \mathcal{I}^{\mathrm{t}}_{\mathrm{i}}(x,\mu) \\ \mathcal{I}^{\mathrm{i}}_{\mathrm{s}}(x,\mu) & \mathcal{I}^{\mathrm{i}}_{\mathrm{t}}(x,\mu) & \mathcal{I}^{\mathrm{i}}_{\mathrm{i}}(x,\mu) \end{pmatrix} \tag{2}$$

where indices (s,t,i) correspond to spatial, temporal, and informational components.

The information tensor is related to the structural differentiation field $\mathcal{S}(x,\mu)$ through the relation:

$$\mathcal{I}^A_B(x,\mu) = \eta^{AC}\langle \mathcal{S}_c(x,\mu) \otimes \mathcal{S}_B(x,\mu)\rangle_{\Omega(x,\delta)} \tag{3}$$

where η^{AC} is the metric tensor in information space, $\otimes$ is the tensor product, and $\langle\cdot\rangle_{\Omega(x,\delta)}$ denotes averaging over a region $\Omega(x,\delta)$ of radius δ around point x.

Axiom 3: Matter as a Projection of Information

Matter in the 3D world is a projection of a complex network of structural differentiations of multidimensional space. Various elementary particles and their properties are manifestations of different informational configurations in higher-dimensional space.

Axiom 4: Law of Information Conservation

The total degree of structural differentiation in a closed multidimensional system remains constant, which manifests in the observed conservation of energy. Fundamental laws of conservation of energy and mass are derived from a more general law of conservation of structural differentiation during transformations and projections between spaces of different dimensionality.

During a projection transformation, information is not actually destroyed but redistributed between observation levels, which manifests as an apparent loss of information for an observer in a lower-dimensional space, while preserving the total information in the complete multidimensional system.

The information tensor satisfies a generalized conservation law:

$$\nabla_A \mathcal{I}^A_B(x,\mu) + \frac{\partial}{\partial\mu}\mathcal{I}^\mu_B(x,\mu) = \mathcal{Q}_B(x,\mu) \tag{4}$$

where ∇_A is the covariant derivative, $\mathcal{I}^\mu_B(x,\mu)$ is the scale component of the information tensor, and $\mathcal{Q}_B(x,\mu)$ is a source term associated with changes in space dimensionality.

When integrating over the entire space in the absence of dimensionality change ($\frac{dD_{eff}(\mu)}{d\mu} = 0$), we obtain the law of conservation of total information:

$$\frac{d}{d\mu}\int_{\mathcal{M}} \mathrm{Tr}(\mathcal{I}^A_B(x,\mu))dV_g(x,\mu) = 0 \tag{5}$$

3.3 Projection Mechanism of Reality

Axiom 5: Projection Postulate

The observable three-dimensional world is a projection of a more fundamental four-dimensional (4D) structure, which in turn is a projection of a five-dimensional space, and so on, forming a hierarchical structure of dimensions. Each n-dimensional space is a projection of an $(n+1)$-dimensional space.

Axiom 6: Projection Operators

There exist mathematical projection operators for the spacetime structure:

1. ***Spatial projection operator $\hat{P}_{n\to m}$, which reduces the dimensionality of space from n to m ($m < n$) while preserving certain structural characteristics and with partial loss of information.***

2. ***Temporal projection operator $\hat{P}^T_{n\to m}$, which transforms the three-component temporal structure $\{\theta_t, \omega_t, \tau_t\}$ of higher dimensions into the observable time of lower dimensions.***

The action of projection operators on physical fields is defined by a system of rules depending on the tensor character of the field and the structure of spaces. For a scalar field ϕ, the general form of the projection transformation is:

$$\phi_m(x) = \int_{\mathcal{M}_n} K_{n\to m}(x,y)\phi_n(y)dV_n(y) \tag{6}$$

where $K_{n\to m}(x,y)$ is the kernel of the projection operator, and $dV_n(y)$ is a volume element in n-dimensional space.
The quantum wave function $\Psi(x,\mu)$ is defined as a projection of the information field $\mathcal{I}(X)$ from higher-dimensional space:

$$\Psi(x,\mu) = \hat{P}_{D_{eff}\to 3}[\mathcal{I}(X)] \tag{7}$$

An entangled quantum state of several particles is defined as a projection of a single object in multidimensional space:

$$\Psi_{ent}(x_1, x_2, ..., x_n, \mu) = \hat{P}_{m\to 3n}[\mathcal{O}(X)] \tag{8}$$

3.4 Scale-Dependent Dimensionality

Axiom 7: Scale Dependence of Dimensionality

The effective dimensionality of space $D_{eff}(\mu)$ as a function of the observation scale μ is mathematically defined by the expression:

$$D_{eff}(\mu) = D_0 + \sum_{i=1}^{n} \alpha_i \cdot f_i\left(\frac{\mu}{\mu_i}\right) \tag{9}$$

where:

- $D_0 = 3$ — base dimensionality of physical space;
- $\mu_i \in [\mu_{min}, \mu_{max}]$ — critical scales at which significant changes in effective dimensionality occur;
- $\alpha_i \in \mathbb{R}$ — amplitude coefficients characterizing the magnitude of dimensionality change;
- $f_i(x)$ — transition functions between scale regimes.

In the standard formulation of SDG, transition functions have the form:

$$f_i(x) = \frac{x^\gamma}{1 + x^\gamma} \cdot e^{-\lambda_i x} \tag{10}$$

where $\gamma > 0$ determines the steepness of the transition, and $\lambda_i \geq 0$ characterizes the rate of attenuation of the influence of scale μ_i with distance from it.

Definition 4 (Scale Parameter of Observation) *The scale parameter μ determines the characteristic size of the region within which a physical system is considered. For* *systems with characteristic size L, the scale parameter is defined as $\mu = L/l_P$, where l_P is the Planck length. The scale parameter varies in the range $\mu \in [\mu_{min}, \mu_{max}]$, where $\mu_{min} \approx 1$ corresponds to the Planck scale, and $\mu_{max} \approx 10^{60}$ corresponds to the scale of the observable Universe.*

Axiom 8: Dimensional Reduction at Macroscales

With increasing spatial scales to cosmological sizes, the metric dimensionality of space is sequentially reduced:

1. ***3D structure transforms into an approximately 2D structure (3→2-reduction)***
2. ***With further increase in scale, a transition to quasi-1D structures occurs (2→1-reduction)***
3. ***In the limit case, quasi-0D structures are formed***

Axiom 9: Monopolar Eversion

The limit states of scale-dependent space dimensionality are connected through a special topological mechanism — monopolar eversion, forming a closed self-referential structure of reality (uroboros). Formally:

$$\lim_{\mu \to \mu_{min}} D_{eff}(\mu) \simeq \lim_{\mu \to \mu_{max}} D_{eff}(\mu) \simeq D_{critical} \tag{11}$$

where $\simeq$ denotes topological equivalence, and $D_{critical}$ is the critical dimensionality characteristic of states at the boundary of the scale range.

Monopolar eversion $\mathcal{M}$ is mathematically defined as a special topological operator establishing a mapping:

$$\mathcal{M} : \mathcal{S}(\mu_{min}) \to \mathcal{S}(\mu_{max}) \tag{12}$$

establishing a one-to-one correspondence between structural differentiations of multidimensional space at the minimum μ_{min} and maximum μ_{max} scales.
This operator has the following key properties:

1. Conservation of information content:

$$I(\Omega, \mu_{min}) = I(\mathcal{M}(\Omega), \mu_{max}) \tag{13}$$

2. Inversion of metric relations: when the operator $\mathcal{M}$ acts, metric relations are inverted, i.e., "internal" becomes "external" and vice versa;

3. Fixed topological characteristic: the index of monopolar eversion

$$\mathrm{Ind}(\mathcal{M}) = \frac{1}{2\pi} \oint_{\gamma} d\theta = \pm 1 \tag{14}$$

is a topological invariant.

4. Self-inversity:

$$\mathcal{M} \circ \mathcal{M} = \mathcal{I} \tag{15}$$

where $\mathcal{I}$ is the identity operator.

3.5 Temporal Composite (Three-Component Time)

Axiom 10: Time as a Measure of Process Activity

Time is viewed not as an absolute quantity but as an expression of the degree of activity of ongoing processes. Different reference frames may observe different rates of time flow related to the intensity of processes in the system.

Axiom 11: Three-Component Structure of Time

Time is characterized not only by duration but also by three fundamental parameters describing it as a temporal composite:

1. ***Chronoangle (θ_t) — a parameter characterizing the relative orientation of the temporal flow in multidimensional space.***
2. ***Chronofrequency (ω_t) — characterizes the rate of processes, determining the pace of system evolution.***
3. ***Chronotopology (τ_t) — describes possible paths of system evolution and their interconnections, determining the structure of cause-effect relationships.***

For the formal description of the temporal composite, the chronotensor $\Theta_{AB}(\mu)$ is introduced, defined as:

$$\Theta_{AB}(\mu) = \begin{pmatrix} \Theta_{\theta\theta}(\mu) & \Theta_{\theta\omega}(\mu) & \Theta_{\theta\tau}(\mu) \\ \Theta_{\omega\theta}(\mu) & \Theta_{\omega\omega}(\mu) & \Theta_{\omega\tau}(\mu) \\ \Theta_{\tau\theta}(\mu) & \Theta_{\tau\omega}(\mu) & \Theta_{\tau\tau}(\mu) \end{pmatrix} \tag{16}$$

where indices $A, B \in \{\theta, \omega, \tau\}$ correspond to the three components of the temporal composite.
The relative contribution of each time component to observable temporal effects depends on the observation scale:

$$w_A(\mu) = \frac{\Theta_{AA}(\mu)}{\sum_B \Theta_{BB}(\mu)} \tag{17}$$

where $w_A(\mu)$ is the relative weight of component $A \in \{\theta, \omega, \tau\}$ at scale μ.

Axiom 12: Scale Dependence of Temporal Parameters

All three components of time (θ_t, ω_t, τ_t) are subject to scale-dependent changes, similar to the dimensionality of space:

$$T(\mu) = \{\theta_t(\mu), \omega_t(\mu), \tau_t(\mu)\} \tag{18}$$

where $T(\mu)$ is a scale-dependent function of time.

Axiom 13: Emergence of Linear Time

The familiar linear, unidirectional time is an emergent property arising at a certain scale of observation, rather than a fundamental characteristic of reality.

3.6 Fundamental Interactions

Axiom 14: Geometric Nature of Interactions

All fundamental interactions have a geometric nature and are manifestations of the geometry of multidimensional space. Physical fields represent projections of curvatures of higher-dimensional space into lower-dimensional spaces.

Axiom 15: Basic Types of SDG Interactions

In SDG, three basic types of interactions underlie all known physical interactions:

1. ***T-interaction (topological coupling) — related to topological aspects of the spacetime structure.***
2. ***R-interaction (resonance coupling) — based on resonance phenomena between different scale levels.***
3. ***X-interaction (chronostructural field) — related to the three-component structure of time.***

Information equations for each type of interaction have the form:

1. T-interaction (topological coupling):

$$\hat{T}[\Psi] = \nabla \times (\mathcal{T}(\mu) \cdot \nabla \times \Psi) = \rho_T \tag{19}$$

   where $\mathcal{T}$ is the tensor of topological coupling, and ρ_T is the density of topological sources.

2. R-interaction (resonance coupling):

$$\hat{R}[\Psi] = \nabla \cdot (\mathcal{R}(\mu, \mu') \cdot \nabla \Psi) = \rho_R \tag{20}$$

   where $\mathcal{R}(\mu, \mu')$ is the tensor of resonance coupling between scales μ and μ'.

3. X-interaction (chronostructural field):

$$\hat{X}[\Psi] = \nabla_T \cdot (\mathcal{X} \cdot \nabla_T \Psi) = \rho_X \tag{21}$$

   where $\mathcal{X}$ is the tensor of the chronostructural field, ∇_T is the temporal gradient.

The general interaction operator $\hat{U}$ is represented as a linear combination of basic operators:

$$\hat{U}(\mu) = \alpha_T(\mu)\hat{T} + \alpha_R(\mu)\hat{R} + \alpha_X(\mu)\hat{X} \tag{22}$$

Axiom 16: Unity of Fundamental Interactions

All known fundamental interactions (gravitational, electromagnetic, strong, weak) are manifestations of the basic T-, R-, and X-interactions in certain scale ranges and under certain conditions.

3.7 Quantum Aspects of SDG

Axiom 17: Geometric Explanation of Quantum Effects

Quantum effects are manifestations of the multidimensional nature of space at the micro-level. Quantum uncertainty is related to the projection of structures of higher dimensionality into lower-dimensional space, and wave functions describe probability distributions of projections of multidimensional objects.

The wave function $\Psi(x, \mu)$ satisfies a generalized Schrödinger equation:

$$i\hbar\frac{\partial\Psi(x,\mu)}{\partial t} = \hat{H}_{eff}(\mu)\Psi(x,\mu) + i\hbar\frac{\partial\Psi(x,\mu)}{\partial\mu}\frac{d\mu}{dt} \tag{23}$$

In the framework of SDG, the uncertainty relation has a generalized form:

$$\Delta x \Delta p \geq \frac{\hbar}{2} \cdot \left(\frac{D_{eff}(\mu)}{3}\right)^{\alpha} \tag{24}$$

with parameter $\alpha > 0$, which reflects the dependence of quantum uncertainty on the effective dimensionality of space.

Axiom 18: Quantum Entanglement as a Projection Effect

Quantum entanglement is explained by the connection of particles in higher-dimensional space, not directly visible in lower-dimensional space. Nonlocal correlations arise due to the preservation of topological connectivity during projection.

Axiom 19: Scale-Dependent Discreteness

The discreteness of spacetime is not limited to the Planck scale but manifests at various scale levels in accordance with the hierarchical structure of dimensional organization of reality.
For each scale level and its corresponding effective dimensionality, specific sizes of 'elementary cells' or 'quanta' of the spacetime structure are characteristic, which decrease when moving deeper into the microworld and increase during the transition to macroscales.

4 Energetic Aspects and Spacetime Control in SDG

In the framework of Scale-Dependent Geometrodynamics, energetic aspects related to changes in space dimensionality, manipulations with temporal composite components, and interaction of spatial and temporal structures have special significance. These aspects not only enrich the theoretical formalism but also open perspectives for practical applications.

4.1 Energetics of Dimensional Transitions

The reduction of effective space dimensionality from $D_{eff}(\mu_1)$ to $D_{eff}(\mu_2)$ (where $\mu_1 < \mu_2$, and $D_{eff}(\mu_1) > D_{eff}(\mu_2)$) is accompanied by energy release. The energy functional of the dimensional state $E[D_{eff}(\mu)]$ defines the energy associated with maintaining a certain effective dimensionality of space:

$$E[D_{eff}(\mu)] = \int_{\mathcal{M}} \mathcal{E}(D_{eff}(\mu), \nabla D_{eff}(\mu))\, dV_g(x, \mu) \tag{25}$$

where $\mathcal{E}$ is the energy density of the dimensional state, defined as:

$$\mathcal{E}(D_{eff}, \nabla D_{eff}) = \lambda_1 (D_{eff} - D_0)^2 + \lambda_2 |\nabla D_{eff}|^2 \tag{26}$$

where λ_1 and λ_2 are constants depending on fundamental physical parameters, and $D_0 = 3$ is the base dimensionality of physical space.
During a dimensional transition, the released energy is determined by the expression:

$$\Delta E(\mu_1 \to \mu_2) = E[D_{eff}(\mu_1)] - E[D_{eff}(\mu_2)] - W_{ext} \tag{27}$$

where W_{ext} is the external work necessary to effect the dimensional transition.

Theorem 3 (Quantization of Dimensional Energy) *In the quantum domain, effective dimensionality is a quantized quantity, and transitions between quantized dimensionality values are accompanied by emission or absorption of elementary energy quanta — dimensons:*

$$\Delta E_{n \to m} = \hbar \omega_{n,m} = \hbar \omega_0 \cdot |D_n - D_m| \tag{28}$$

where $\omega_{n,m}$ is the characteristic frequency of transition between dimensional states n and m, and ω_0 is the fundamental frequency of dimensional oscillations.

Observation 3 (Energetic Effects of Dimensional Transitions) *Dimensional transitions are accompanied by the following energetic effects:*

1. ***Change in interaction energy**. When the effective dimensionality of space changes, the character of physical interactions is modified. For example, the Coulomb potential in a space of dimensionality D has the form $V(r) \propto r^{-(D-2)}$, which leads to a change in interaction energy during dimensional transitions.*

2. ***Change in entropy**. Dimensional transitions are accompanied by changes in the available phase space and, consequently, the entropy of the system. When*

transitioning to a space of higher dimensionality, the number of available degrees of freedom increases, leading to an increase in entropy.

3. ***Quantum dimensional fluctuations****. In the vicinity of critical scales μ_i, where significant changes in effective dimensionality occur, quantum fluctuations of dimensionality arise, accompanied by radiation and absorption of dimensons.*

Corollary 1 (Relation between Dimensional Energy and Cosmological Phenomena) *The change in effective dimensionality of space on cosmological scales provides a natural mechanism for generating the observed effects of dark energy. The vacuum energy density ρ_Λ is related to the gradient of effective dimensionality by the relation:*

$$\rho_\Lambda(\mu) \approx \frac{\lambda_c}{8\pi G}\left|\frac{dD_{eff}(\mu)}{d\mu}\right|^2 \tag{29}$$

where λ_c is a constant depending on the fundamental parameters of the theory, and G is the gravitational constant.

4.2 Temporal Energetics

Manipulations with temporal composite components can lead to energy release. The energy functional of the temporal state $E[T(\mu)]$ defines the energy associated with maintaining a certain configuration of the temporal composite:

$$E[T(\mu)] = \int_{\mathcal{M}} \mathcal{E}_T(T(\mu), \nabla T(\mu))\, dV_g(x,\mu) \tag{30}$$

where $\mathcal{E}_T$ is the energy density of the temporal state, defined as:

$$\mathcal{E}_T(T(\mu), \nabla T(\mu)) = \lambda_\theta|\nabla\theta_t|^2 + \lambda_\omega|\nabla\omega_t|^2 + \lambda_\tau|\nabla\tau_t|^2 + V_T(T(\mu)) \tag{31}$$

where λ_θ, λ_ω, and λ_τ are coupling constants for the corresponding components of the temporal composite, and $V_T(T(\mu))$ is the potential energy of the temporal state.

Theorem 4 (Energetics of Temporal Loops) *A special case of manipulation with the temporal composite is the creation of closed temporal structures (temporal loops) through purposeful modification of chronotopology τ_t. A temporal loop is mathematically defined as:*

$$\gamma_T = \{T(s) \,|\, s \in [0,1], T(0) = T(1)\} \tag{32}$$

with non-trivial homotopy class $[\gamma_T] \neq [0]$.
The energy associated with temporal loop γ_T is determined by the expression:

$$E[\gamma_T] = \oint_{\gamma_T} \mathcal{E}_T(T(s), \nabla T(s))\, ds + \Phi_T[\gamma_T] = \oint_{\gamma_T} \mathcal{E}_T(T(s), \nabla T(s))\, ds + \hbar\omega_0 \cdot Wind(\gamma_T) \tag{33}$$

where the integral is taken over the closed contour γ_T in the space of the temporal composite, $\Phi_T[\gamma_T]$ is the topological invariant of the loop, $Wind(\gamma_T)$ is the winding number of the loop, and $\hbar\omega_0$ is the quantum of temporal energy.

Corollary 2 (Energy Extraction from Temporal Structures) *Extraction of energy from a temporal loop occurs during its annihilation (topological collapse), when the homotopy class* $[\gamma_T]$ *transforms into the trivial* $[0]$. *The released energy equals* $E_{released} = E[\gamma_T]$.

Observation 4 (Energetic Properties of Temporal Configurations) *Temporal energetics manifests in the following physical effects:*

1. ***Quantization of temporal energy****. There exist discrete energy levels corresponding to different configurations of the temporal composite. Transitions between these levels are accompanied by emission or absorption of quanta of temporal energy — chronotons.*

2. ***Resonant temporal phenomena****. At certain relationships between the components of the temporal composite, resonant phenomena arise, accompanied by significant amplification of energy exchange between different scale levels.*

3. ***Temporal barriers****. There exist energy barriers between different temporal configurations, overcoming which requires the application of external energy or quantum-mechanical tunneling.*

Property 1 (Relation of Temporal Energy to Physical Processes) *Temporal energy, associated with the configuration of the temporal composite, manifests in physical processes as follows:*

1. *Chronoangle gradient* $\nabla\theta_t$ *generates an effective field interacting with quantum phase and particle spin.*

2. *Chronofrequency gradient* $\nabla\omega_t$ *creates an effective force modifying system dynamics (similar to the gradient of gravitational potential).*

3. *Chronotopology gradient* $\nabla\tau_t$ *affects quantum correlations and entanglement, modifying information exchange between systems.*

4.3 Interrelation of Space and Time

Axiom 20: Interrelation of Metric Structure of Space and Temporal Composite

In scale-dependent geometrodynamics, there exists a fundamental bidirectional connection between the metric structure of space and the temporal composite. Local controlled change of one entails a corresponding change in the other, which defines a unified spacetime structure depending on the observation scale μ.

Mathematically, this connection is expressed through a system of interrelated operators:

1. **Operator of temporal modification** $\mathcal{T}$, defining the influence of changes in spatial metric on the temporal composite:

$$\delta\Theta_{AB}(\mu, x) = \mathcal{T}\left[\delta g_{ij}(\mu, x)\right] = \int_{\Omega} K_{ij}^{AB}(\mu, x, x')\delta g_{ij}(\mu, x')\, d^n x' \tag{34}$$

2. **Operator of spatial modification** $\mathcal{S}$, defining the influence of changes in the temporal composite on the spatial metric:

$$\delta g_{ij}(\mu, x) = \mathcal{S}\left[\delta\Theta_{AB}(\mu, x)\right] = \int_{\Omega} H_{AB}^{ij}(\mu, x, x')\delta\Theta_{AB}(\mu, x')\, d^n x' \tag{35}$$

where $K_{ij}^{AB}(\mu, x, x')$ and $H_{AB}^{ij}(\mu, x, x')$ are the corresponding kernels of integral operators, Ω is the region of space in which modification occurs, and n is the dimensionality of space at scale μ.

For operators $\mathcal{T}$ and $\mathcal{S}$, the principle of mutual consistency holds:

$$\mathcal{T} \circ \mathcal{S} \circ \mathcal{T} = \mathcal{T} \quad \text{and} \quad \mathcal{S} \circ \mathcal{T} \circ \mathcal{S} = \mathcal{S} \tag{36}$$

The connection between chronotensor $\Theta_{AB}(\mu)$ and scale-dependent effective dimensionality $D_{eff}(\mu)$ is expressed through the following relation:

$$D_{eff}(\mu) = D_0 + \gamma \cdot \mathrm{Tr}\left[\Theta_{AB}(\mu) \cdot M^{AB}\right] \tag{37}$$

where D_0 is the base dimensionality, γ is the coupling constant, and M^{AB} is the scale sensitivity matrix.

Axiom 21: Principle of Temporal-Spatial Control

In scale-dependent geometrodynamics, there exists a fundamental possibility of purposeful control of both the metric structure of space and the components of the temporal composite through their interconnection. For any local region of space, there exist physical mechanisms allowing to modify spacetime characteristics within specified limits.

The principle of temporal-spatial control includes the following key aspects:

1. Mechanisms of Spacetime Control
Spacetime characteristics control is exercised through three fundamental mechanisms:
a) Temporal modulation: impact on components Θ_{AB} through generation of temporal oscillations with operator $\mathcal{M}_T$:

$$\mathcal{M}_T[\Theta_{AB}](\mu, x, t) = \Theta_{AB}(\mu, x) + A_{AB}(\mu, x) \cdot f(t, \omega_{AB}) \tag{38}$$

where A_{AB} is the amplitude function, and f is a periodic function with frequencies ω_{AB}.
b) Spatial interference: generation of interference patterns in metric structure with operator $\mathcal{M}_S$:

$$\mathcal{M}_S[g_{ij}](\mu, x) = g_{ij}(\mu, x) + \sum_{n=1}^{N} B_{ij}^{(n)}(\mu) \cos(k_n \cdot x + \phi_n) \tag{39}$$

where $B_{ij}^{(n)}$ are mode amplitudes, k_n are wave vectors, ϕ_n are phases.
c) Resonant conjugation: synchronization of spatial and temporal modifications with operator $\mathcal{M}_{ST}$:

$$\mathcal{M}_{ST}[g_{ij}, \Theta_{AB}](\mu, x, t) = \mathcal{F}\left[\mathcal{M}_S[g_{ij}](\mu, x), \mathcal{M}_T[\Theta_{AB}](\mu, x, t), \xi(\mu)\right] \tag{40}$$

where $\mathcal{F}$ is the conjugation functional, and $\xi(\mu)$ is the scale-dependent coupling parameter.

2. Limits and Constraints of Control
There exist fundamental limitations on achievable configurations:
a) Structural stability condition:

$$\|\delta g_{ij}(\mu, x)\| \leq \eta_S(\mu) \quad \text{and} \quad \|\delta\Theta_{AB}(\mu, x)\| \leq \eta_T(\mu) \tag{41}$$

where $\eta_S(\mu)$ and $\eta_T(\mu)$ are scale-dependent stability limits.
b) Informational coherence condition:

$$\mathcal{I}[g'_{ij}, \Theta'_{AB}] - \mathcal{I}[g_{ij}, \Theta_{AB}] \leq \Delta\mathcal{I}_{max}(\mu, V) \tag{42}$$

where $\mathcal{I}$ is the information functional, and $\Delta\mathcal{I}_{max}(\mu, V)$ is the maximally permissible change in information in volume V at scale μ.

Theorem 5 (Energy Costs of Spacetime Control) *The energy E necessary for changing the spacetime configuration is determined by the action functional:*

$$E[g_{ij} \to g'_{ij}, \Theta_{AB} \to \Theta'_{AB}] = \int_V \varepsilon(\mu, \delta g_{ij}, \delta\Theta_{AB})\, d^n x \tag{43}$$

where ε is the energy density of modification, and integration is performed over the volume V in which modification occurs.
The energy density of modification is subject to the principle of minimum action:

$$\varepsilon(\mu, \delta g_{ij}, \delta\Theta_{AB}) \geq \kappa(\mu) \cdot \|\delta g_{ij}\| \cdot \|\delta\Theta_{AB}\| \cdot \sqrt{\det(g_{ij})} \tag{44}$$

where $\kappa(\mu)$ is the scale-dependent coefficient of energy efficiency.

Corollary 3 (Resonant Energy Economy) *For oscillatory modifications, there exists a regime of resonant energy economy:*

$$E_{res} \approx \frac{E_0}{\mathcal{Q}(\mu, \omega)} \tag{45}$$

where E_0 is the base energy expenditure, and $\mathcal{Q}(\mu, \omega)$ is the resonance quality factor, depending on scale μ and oscillation frequency ω.

4.4 Practical Aspects of SDG Energetics

Observation 5 (Technological Applications of SDG Energetic Aspects) *The energetic aspects of SDG open perspectives for developing new technologies:*

1. ***Energy systems based on dimensional transitions****. Theoretically, it is possible to create devices extracting energy from controlled dimensional transitions in specially prepared materials or quantum systems.*

2. ***Temporal energetics****. Manipulations with the temporal composite can underlie new approaches to energy generation and transformation, in particular, through creation and annihilation of temporal loops.*

3. ***Resonant technologies****. The use of resonant phenomena arising from joint modulation of spatial and temporal characteristics for energy-efficient technologies of energy transformation and transmission.*

4. ***Protective systems****. Creation of "temporal shields" and other protective contours, screening certain areas from external spacetime disturbances based on the principles of temporal-spatial control.*

Theorem 6 (Transformational Energetics) *The joint use of dimensional transitions and manipulations with the temporal composite allows realization of transformational energetics — an approach in which energy is extracted from purposeful transformations of the spacetime structure. The efficiency of such a system is determined by the expression:*

$$\eta_{trans} = \frac{E_{out}}{E_{in}} = \frac{\Delta E_{dim} + \Delta E_{temp}}{E_{control}} > 1 \tag{46}$$

where ΔE_{dim} is the energy released during dimensional transitions, ΔE_{temp} is the energy released during transformation of the temporal composite, and $E_{control}$ is the energy spent on controlling these processes.

The energetic aspects of SDG presented provide a theoretical foundation both for fundamental research and for developing promising technologies based on controlling the spacetime structure of reality.

5 Cosmological Aspects of SDG

Axiom 22: Origin of the Universe

The Big Bang represents a projection of the monopolar eversion process in multidimensional space onto the observable three-dimensional world. This is not the emergence of the Universe 'from nothing,' but a manifestation of a fundamental topological transformation connecting the limit states of scale-dependent dimensionality, observed in our projection as the cosmological Big Bang.

Axiom 23: Nature of Dark Matter

Dark matter is a projection effect — a manifestation of the geometry of higher-dimensional space when projected into the three-dimensional world. This explains the absence of direct detection of dark matter particles, despite the observed gravitational effects.

Axiom 24: Nature of Dark Energy

Dark energy is a manifestation of the elasticity of multidimensional space during projection curvature. This explains the observed accelerated expansion of the Universe without introducing exotic forms of energy.

Axiom 25: Large-Scale Structure of the Universe

The large-scale structure of the Universe (cosmic web, superclusters of galaxies, voids) is a manifestation of scale-dependent dimensional reduction at cosmological scales: from 3D structure to approximately 2D structure (3→2-reduction), further to quasi-1D structures (2→1-reduction), and, in the limit, to quasi-0D structures.

5.1 Large-Scale Structure of the Universe and Dimensional Reduction

SDG proposes a new interpretation of the origin of the large-scale structure of the Universe, viewing it as a manifestation of sequential dimensional reduction at various scales.

Theorem 7 (Hierarchy of Large-Scale Structure as a Consequence of Dimensional Reduct *According to SDG, the observed hierarchy of cosmic structures is a direct consequence of sequential dimensional reduction with increasing scale:*

1. *At scales up to ~ 20 Mpc — approximately three-dimensional distribution of galaxies (3D structure) with effective dimensionality $D_{eff} \approx 3$.*

2. *At scales $\sim 20 - 100$ Mpc — formation of walls and filaments with predominance of two-dimensional structures (quasi-2D structure) with effective dimensionality $D_{eff} \approx 2.1 - 2.5$.*

3. *At scales* $\sim 100 - 300$ *Mpc — dominance of one-dimensional filaments (quasi-1D structure) with effective dimensionality* $D_{eff} \approx 1.3 - 1.8$.

4. *At scales* > 300 *Mpc — formation of isolated nodes (quasi-0D structure) with effective dimensionality* $D_{eff} \approx 0.8 - 1.2$.

Proof Considering the dependence of effective dimensionality $D_{eff}(\mu)$ on scale μ, gravitational instability in the expanding Universe leads to the formation of structures whose morphology is determined by the local effective dimensionality of space. In particular, at scales where $D_{eff} \approx 2$, gravitational collapse predominantly occurs in one direction, forming flat structures (walls). At scales where $D_{eff} \approx 1$, collapse occurs in two directions, forming filaments. This naturally leads to the observed hierarchy of structures. □

Definition 5 (Scale-Dependent Fractal Dimension of Large-Scale Structure) *The scale-dependent fractal dimension of the Universe's large-scale structure* $D_F(\lambda)$ *can be approximated by the following function:*

$$D_F(\lambda) = 3 - \sum_{i=1}^{3} \frac{\alpha_i \cdot (\lambda/\lambda_i)^{\beta_i}}{1 + (\lambda/\lambda_i)^{\beta_i}} \cdot \frac{1}{1 + (\lambda/\lambda_{i+1})^{\gamma_i}} \tag{47}$$

where λ *is the spatial scale,* $\alpha_i \approx 0.5 - 1.0$ *are the amplitudes of dimensionality transitions,* $\beta_i \approx 2 - 4$ *and* $\gamma_i \approx 2 - 3$ *are exponents characterizing the transition rates, and* λ_i *are critical transition scales:* $\lambda_1 \approx 20$ *Mpc,* $\lambda_2 \approx 100$ *Mpc,* $\lambda_3 \approx 300$ *Mpc,* $\lambda_4 \approx 1000$ *Mpc.*

5.2 Scale-Dependent Modifications of Cosmological Formulas

SDG predicts specific modifications to standard cosmological formulas, accounting for the effects of dimensional reduction at various scales.

Theorem 8 (Modified Friedmann Equation)

In the framework of SDG, the standard Friedmann equation is modified to account for the effects of scale-dependent dimensionality:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3} + F(a, \dot{a}, D_{eff}) \tag{48}$$

where a *is the scale factor,* ρ *is the matter density,* k *is the curvature parameter,* Λ *is the cosmological constant, and* $F(a, \dot{a}, D_{eff})$ *is an additional term dependent on effective dimensionality:*

$$F(a, \dot{a}, D_{eff}) = \frac{8\pi G}{3}\rho \cdot f(D_{eff}) + \frac{\Lambda c^2}{3} \cdot g(D_{eff}) \tag{49}$$

where $f(D_{eff})$ *and* $g(D_{eff})$ *are functions characterizing the influence of dimensional reduction on the dynamics of matter and dark energy, respectively.*

Theorem 9 (Modified Scale-Distance Relationships) *SDG predicts specific modifications to scale-distance relationships, connected with the effects of dimensional reduction:*

$$d_L(z) = d_{L,\Lambda CDM}(z) \cdot [1 + \delta_d \cdot q(z)] \tag{50}$$

where $d_L(z)$ is the luminosity distance, $d_{L,\Lambda CDM}(z)$ is the luminosity distance in the standard ΛCDM model, $\delta_d \approx 0.05 - 0.1$ is the modification amplitude, and $q(z)$ is a function dependent on redshift.

Observation 6 (Comparison with Observational Anomalies) *The modified cosmological formulas of SDG can explain a number of observational anomalies:*

1. *The Hubble tension — the discrepancy between values of the Hubble constant measured via the cosmic microwave background ($H_0 \approx 67 - 68$ km/s/Mpc) and via local distance indicators ($H_0 \approx 73 - 74$ km/s/Mpc), can be explained by scale-dependent modifications to scale-distance relationships.*

2. *Anomalies in the power spectrum of cosmic microwave background fluctuations at large angular scales may be connected with the influence of dimensional reduction in the early stages of Universe evolution.*

3. *The observed deficiency of matter clustering at scales > 100 Mpc compared to predictions of the standard ΛCDM model can be explained by the effects of dimensional reduction at corresponding scales.*

5.3 SDG Predictions Regarding Gravitational Waves

The discovery of gravitational waves by the LIGO experiment in 2015 and subsequent observations of black hole and neutron star mergers opened a new era in observational astronomy. SDG offers specific predictions regarding gravitational waves that can be tested using data from LIGO, Virgo, and future gravitational wave observatories.

Theorem 10 (Modification of the Law of Gravitational Wave Propagation)

SDG predicts a scale-dependent modification of the law of gravitational wave propagation. The speed of gravitational wave propagation v_{GW} depends on the wavelength λ_{GW} and distance r:

$$v_{GW}(\lambda_{GW}, r) = c \cdot [1 + \delta_{GW} \cdot f(\lambda_{GW}/\lambda_0, r/r_0)] \tag{51}$$

where c is the speed of light, $\delta_{GW} \approx 10^{-15} - 10^{-14}$ is the modification amplitude, and $f(\lambda_{GW}/\lambda_0, r/r_0)$ is a function dependent on the ratio of wavelength to characteristic scale $\lambda_0 \approx 10^8 - 10^9$ m and the ratio of distance to characteristic scale $r_0 \approx 10^{20} - 10^{21}$ m.

Corollary 4 (Frequency Dispersion of Gravitational Waves) *SDG predicts weak frequency dispersion of gravitational waves — dependence of propagation speed on frequency. For frequencies $f_{GW} = c/\lambda_{GW}$ this is expressed as:*

$$v_{GW}(f_{GW}) = c \cdot [1 + \delta_{GW} \cdot \phi(f_{GW}/f_0)] \tag{52}$$

where $\phi(f_{GW}/f_0)$ is a function dependent on the ratio of frequency to characteristic frequency $f_0 = c/\lambda_0 \approx 0.3 - 3$ Hz.

Theorem 11 (Non-standard Polarizations of Gravitational Waves) *In the framework of SDG, the presence of additional polarization modes of gravitational waves is predicted, beyond the two tensor modes predicted by general relativity. These additional modes are connected with the projection of wave disturbances from higher-dimensional space:*

1. *Scalar "breathing" mode, associated with isotropic volume changes.*
2. *Scalar "longitudinal" mode, associated with anisotropic changes along the direction of propagation.*
3. *Vector modes ("x-mode" and "y-mode"), associated with shear deformations perpendicular to the direction of propagation.*

The amplitude of these additional modes is proportional to the deviation of effective dimensionality from $D_{eff} = 3$:

$$A_{non-tensor} \propto |D_{eff}(\mu_{GW}) - 3| \tag{53}$$

where μ_{GW} is the characteristic scale of the gravitational wave.

Observation 7 (Verification through LIGO/Virgo Observations) *LIGO/Virgo observations allow testing SDG predictions about the modification of gravitational wave emission:*

1. *Analysis of the mass distribution of black holes observed in gravitational wave events can reveal deviations from general relativity predictions related to emission modification.*
2. *Measurements of orbital angular momentum reduction in binary black hole systems may show deviations from general relativity predictions related to modified emission power.*
3. *Observations of mergers of very massive black holes ($M > 100M_{\odot}$) will be especially informative for testing SDG predictions, since at such scales the most notable effects of dimensional reduction are expected.*

6 Methodological Principles of SDG

Axiom 26: Projection Principle

All physical phenomena in the 3D world are projections of processes in multidimensional space. The observed physical laws in the 3D world represent projections of more fundamental laws of multidimensional space.

Axiom 27: Scale Symmetry Principle

Physical laws are invariant with respect to scale transformations, provided that the change in effective dimensionality of space $D_{eff}(\mu)$ is accounted for. There exist deep connections between phenomena at different scales, and the microworld and macroworld are connected by a unified geometrodynamic structure.

Axiom 28: Information Integrity Principle

Information is a fundamental entity determining the structure of multidimensional space. Laws of information conservation underlie all physical laws. There exists a deep connection between information, energy, and the structure of spacetime.

Axiom 29: Three-Component Temporality Principle

Time is characterized by three independent but interconnected components (chronoangle, chronofrequency, and chronotopology), forming a unified temporal structure dependent on the observation scale.

6.1 Monopolar Eversion and the Uroboros Concept

Monopolar eversion represents a special topological mechanism that plays a central role in SDG, connecting the limit states of scale-dependent dimensionality and providing a closed self-referential structure of reality, termed uroboros in the theory.
Formally, monopolar eversion effects the mapping:

$$\mathcal{M} : \lim_{\mu \to \mu_{min}} D_{eff}(\mu) \to \lim_{\mu \to \mu_{max}} D_{eff}(\mu) \tag{54}$$

where $\mathcal{M}$ is the monopolar eversion operator, μ_{min} and μ_{max} are the minimum and maximum scales, respectively, and $D_{eff}(\mu)$ is the effective dimensionality of space at scale μ.
Monopolar eversion can be conceptually represented as a "stitching" of reality at its limit scales. In the microworld, at scales close to Planckian, the effective dimensionality of space increases, reaching its maximum at μ_{min}. Symmetrically, at the largest cosmological scales, the effective dimensionality decreases to minimum values at μ_{max}. Monopolar eversion establishes topological equivalence between these extreme states of scale-dependent dimensionality, forming a closed structure of reality.
Uroboros (a term borrowed from the ancient symbolism of a snake biting its tail) in the context of SDG means the fundamental closure and self-referentiality of the structure of reality. This fundamental property indicates that reality has no external "edges" or boundaries — it closes upon itself through monopolar eversion. This concept has profound implications, including:

1. Absence of the need for "initial conditions" or an "external observer" — reality is completely self-consistent and self-referential.

2. Emergence of cause-effect cycles at a fundamental level, which, however, do not violate causality in the observed three-dimensional world due to the projective nature of observable phenomena.

3. Creation of conditions for information integrity — information is neither "lost" nor "emerges from nothing," but circulates within the closed structure, only changing its manifestations at different scale levels.

Monopolar eversion also plays a key role in SDG cosmology. The Big Bang in this interpretation is not an initial singularity, but a projection of the monopolar eversion process into the observable three-dimensional world. This explains a number of cosmological paradoxes, including the problem of the Universe's initial conditions and the homogeneity of cosmic microwave background radiation.

7 Visualization of Key Concepts

This section presents descriptions of the main concepts of Scale-Dependent Geometrodynamics, designed to facilitate understanding of the fundamental principles of the theory.

7.1 Scale-Dependent Dimensionality of Space

One of the key provisions of SDG is the concept of effective dimensionality of space $D_{eff}(\mu)$ as a function of the observation scale μ. Graphically, this can be represented as a curve that:

- Takes maximum values ($D_{eff} > 3$) at Planckian and quantum scales
- Stabilizes near the value $D_{eff} \approx 3$ at human scales (corresponding to our everyday experience of three-dimensional space)
- Sequentially decreases ($D_{eff} < 3$) during the transition to galactic and cosmological scales
- Closes through a special mechanism — monopolar eversion, connecting the limit states $\lim_{\mu \to \mu_{min}} D_{eff}(\mu)$ and $\lim_{\mu \to \mu_{max}} D_{eff}(\mu)$, forming a closed self-referential structure (uroboros)

The effective dimensionality function $D_{eff}(\mu)$ can be graphically represented as a continuous curve with two asymptotic limits:

$$D_{eff}(\mu) \approx \begin{cases} D_{max} \cdot (1 - e^{-\alpha(\mu_0/\mu)^{\beta}}), & \mu \ll \mu_0 \\ D_0, & \mu \approx \mu_0 \\ D_{min} + (D_0 - D_{min}) \cdot e^{-\gamma(\mu/\mu_0)^{\delta}}, & \mu \gg \mu_0 \end{cases} \tag{55}$$

where $\alpha, \beta, \gamma, \delta > 0$ are parameters determining the rate of change of effective dimensionality in various scale regimes, and μ_0 is the characteristic scale at which $D_{eff}(\mu_0) = D_0 = 3$.

7.2 Projection Mechanism of Reality

SDG views the observable three-dimensional world as a projection of more fundamental multidimensional structures. Visually, this process can be represented as:

- An object existing in a space of higher dimensionality $D_{eff} > 3$ (for example, in 4D or 5D space)
- A projection operator $\hat{P}_{D_{eff} \to 3}$ mapping this object into observable three-dimensional space

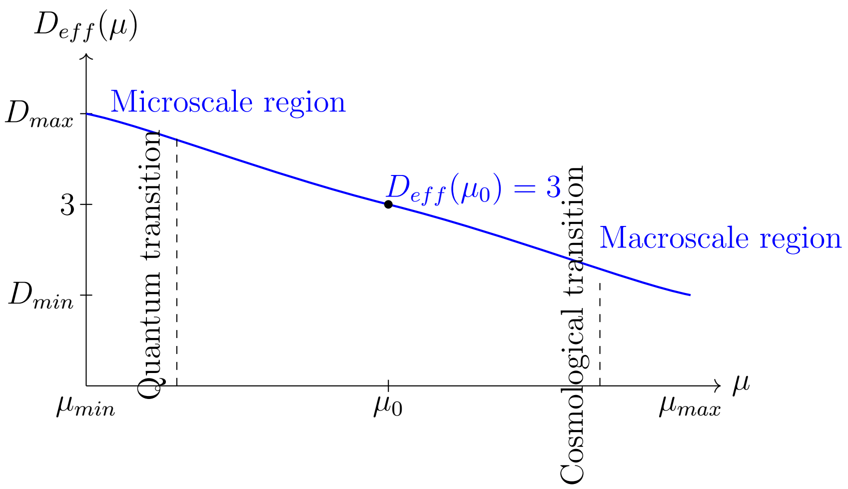

Figure 1: Schematic representation of the effective dimensionality function $D_{eff}(\mu)$ depending on scale μ.

- A projection of the object in the observable 3D world, which preserves some properties of the original object, but loses some information in the projection process

A key aspect is that quantum effects, such as uncertainty, entanglement, and the wave nature of particles, arise due to the incompleteness of this projection and the corresponding loss of information during the transition from multidimensional structures to three-dimensional representation.

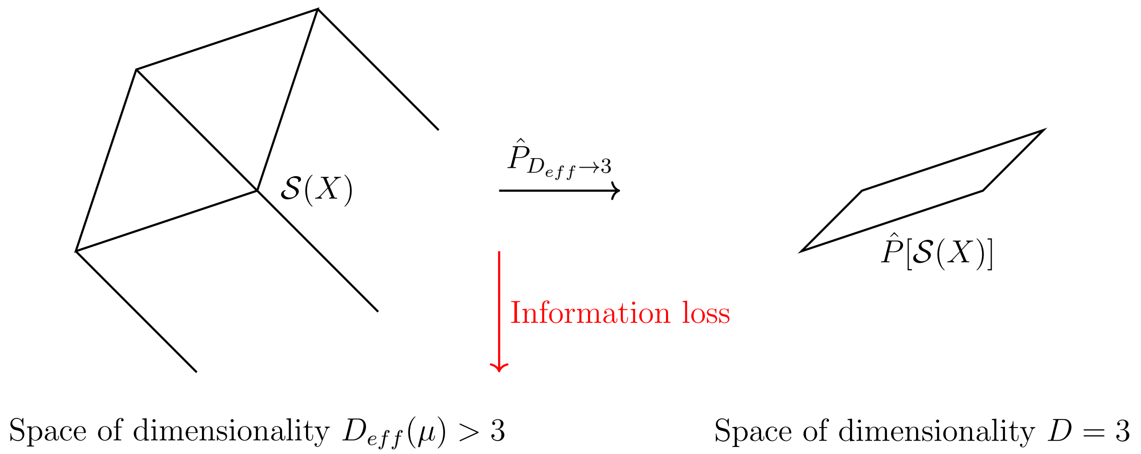

Figure 2: Schematic visualization of the projection mechanism.

8 Comparison of SDG with Existing Theoretical Approaches

8.1 SDG and String Theory

String theory, the leading candidate for a "theory of everything," has some common elements with SDG, particularly the assumption of multidimensionality of space.

However, there are fundamental differences between these approaches:

1. **Nature of dimensions**. In string theory, additional dimensions (usually 6 or 7) are considered compactified to sub-Planckian scales and do not depend on the scale of observation. In SDG, the effective dimensionality of space $D_{eff}(\mu)$ is a function of scale, increasing in the microworld and decreasing in the macroworld.

2. **Basic objects**. In string theory, the fundamental objects are one-dimensional strings (or multidimensional branes in M-theory). In SDG, the primary category is information as structural differentiation of multidimensional space, from which all observable physical objects are formed in the process of projection.

3. **Explanation of quantum phenomena**. String theory assumes an inherently quantized nature of fundamental objects. SDG views quantum effects as manifestations of projection processes from higher-dimensional spaces.

4. **Temporal structure**. String theory maintains the classical one-dimensional concept of time. SDG introduces the revolutionary concept of three-component time, including chronoangle, chronofrequency, and chronotopology.

8.2 SDG and Loop Quantum Gravity

Loop quantum gravity (LQG) — another approach to quantum gravity theory — also has some parallels with SDG, but differs significantly:

1. **Quantization of space**. LQG assumes a discrete structure of spacetime at the Planck scale. SDG also recognizes the discreteness of spacetime but makes it scale-dependent: each scale level and corresponding effective dimensionality has its characteristic sizes of "quanta" of spacetime structure.

2. **Space dimensionality**. LQG works in standard four-dimensional spacetime. SDG postulates scale-dependent effective dimensionality, varying from microscopic to cosmological scales.

3. **Temporal structure**. LQG encounters the problem of time, which fundamentally arises in canonical approaches to quantum gravity. SDG resolves this problem through the three-component concept of time, explaining the emergence of observable linear time.

8.3 Fundamental Novelty of SDG

Unlike the approaches mentioned above, SDG proposes a fundamentally new paradigm based on the following unique elements:

1. **Scale-dependent effective dimensionality of space** as a function $D_{eff}(\mu)$, describing continuous change in dimensionality from micro- to macroscales.

2. **Three-component structure of time**, including chronoangle, chronofrequency, and chronotopology, which revolutionarily changes the concept of the temporal aspect of reality.

3. **Projection mechanism of observable phenomena**, explaining the formation of the three-dimensional world through projections of higher-dimensional structures.

4. **Information primacy**, postulating information as a fundamental entity from which matter and energy are formed through projection mechanisms.

5. **Monopolar eversion** as a mechanism connecting the limit states of scale-dependent dimensionality and providing a closed self-referential structure of reality.

6. **New triad of basic interactions**: T-interaction (topological coupling), R-interaction (resonance coupling), and X-interaction (chronostructural field), from which all known fundamental interactions are derived.

9 Connection to Fundamental Problems in Physics

9.1 Overcoming Contradictions Between Quantum Mechanics and Gravity

One of the most fundamental problems in modern theoretical physics is the incompatibility between quantum mechanics and general relativity. Within SDG, this problem finds a natural resolution through understanding the scale-dependent structure of spacetime.
In SDG, quantum effects are viewed as manifestations of projection processes related to higher dimensions. Quantum uncertainty and the probabilistic nature of quantum mechanics arise as natural consequences of projecting higher-dimensional structures into lower-dimensional space. On the other hand, gravity represents a manifestation of spacetime curvature, which is also connected with projection effects.
Accounting for scale-dependent effective dimensionality of space allows unifying these two aspects in a single formalism. At microscopic scales where quantum effects manifest, the effective dimensionality of space is higher, leading to specific quantum phenomena. At macroscopic scales, the effective dimensionality decreases, corresponding to classical gravitational description. Thus, the apparent incompatibility between quantum mechanics and gravity is resolved by understanding them as different projection manifestations of a unified multidimensional structure of reality at different scales.

9.2 Interpretation of Dark Matter and Dark Energy

According to SDG, dark matter and dark energy are not new forms of matter or energy but manifestations of geometric effects associated with scale-dependent changes in the effective dimensionality of space.

9.2.1 Dark Matter as a Manifestation of Dimensional Reduction

Within SDG, dark matter is interpreted as a manifestation of partial dimensional reduction at galactic scales. At these scales, the effective dimensionality of space begins to decrease ($D_{eff} < 3$), leading to modification of the law of gravitational interaction.

The standard inverse square law for gravitational force $F \propto 1/r^2$ is valid only for three-dimensional space. In a space with effective dimensionality D_{eff}, gravitational force changes as $F \propto 1/r^{D_{eff}-1}$. Thus, at $D_{eff} < 3$, the force decreases with distance more slowly than in the standard three-dimensional case, manifesting as an apparent enhancement of gravity usually attributed to the presence of dark matter.
This interpretation naturally explains:

- Flat rotation curves of galaxies without introducing additional matter
- Absence of direct detection of dark matter particles, despite numerous attempts
- Observed correlation between the distribution of visible matter and "dark matter" effects

9.2.2 Dark Energy as a Manifestation of Multidimensional Space Elasticity

Dark energy within SDG is viewed as a manifestation of the elasticity of multidimensional space during projection curvature. At cosmological scales, the effective dimensionality of space continues to decrease, creating an effect of "elastic reaction" of multidimensional space, manifesting as an anti-gravitational effect usually attributed to dark energy.
This interpretation allows explaining:

- Accelerated expansion of the Universe as a natural consequence of spacetime structure
- Proximity of the observed density of dark energy to the critical density of the Universe
- Isotropy and homogeneity of dark energy

SDG predicts that effective "dark energy" should have a specific evolution with redshift, differing from the predictions of the ΛCDM model with a cosmological constant.

9.3 Geometric Interpretation of Quantum Effects

SDG offers a fundamentally new view of quantum phenomena, regarding them as manifestations of projection mechanisms from higher-dimensional spaces into the observable three-dimensional world. This approach allows giving a geometric interpretation to the main quantum effects.

9.3.1 Quantum Uncertainty

Within SDG, quantum uncertainty arises as an inevitable consequence of the projection of multidimensional structures into lower-dimensional space. During such projection, partial loss of information occurs, manifesting as a fundamental uncertainty in measuring conjugate observables. Mathematically, this is expressed as:

$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2} \cdot \left(\frac{D_{eff}(\mu)}{3}\right)^{\alpha} \tag{56}$$

where $\alpha > 0$ is a parameter dependent on the character of projection. Thus, Heisenberg's uncertainty relation receives a natural geometric interpretation within SDG.

9.3.2 Quantum Entanglement

Quantum entanglement in SDG is viewed as a manifestation of topological connectivity of objects in higher-dimensional space. Entangled particles represent projections of a single multidimensional object into observable three-dimensional space. Formally, this is written as:

$$|\Psi_{AB}\rangle = \hat{P}_{D_{eff}\to 3+3}[|\Phi_{AB}\rangle] \tag{57}$$

where $|\Phi_{AB}\rangle$ is a unified state in higher-dimensional space $D_{eff}(\mu)$, and $\hat{P}_{D_{eff}\to 3+3}$ is a projection operator into double three-dimensional space.
This explanation naturally resolves the "Einstein-Podolsky-Rosen paradox," as nonlocal correlations of entangled particles arise not due to instantaneous information transfer between them, but due to their original connectivity in multidimensional space.

9.4 Origin and Evolution of the Universe

SDG proposes a new cosmological model that differently interprets the origin and evolution of the Universe. According to the theory, the Big Bang is not the beginning of everything but represents a projection of a fundamental topological transformation in multidimensional space — monopolar eversion.
Monopolar eversion connects the limit states of scale-dependent dimensionality, creating a closed self-referential structure of reality. In projection onto observable three-dimensional space, this process is perceived as the cosmological Big Bang and subsequent expansion of the Universe.
The large-scale structure of the Universe — cosmic web, galaxy superclusters, voids — is a direct consequence of dimensional reduction processes at cosmological scales. During the transition from micro- to macroscales, the effective dimensionality of space sequentially decreases, forming the observed hierarchy of cosmic structures.
Such a model resolves a number of cosmological paradoxes, including the horizon problem and the flatness problem of the Universe, without the need to introduce an inflationary stage. Additionally, it naturally explains the asymmetry between matter and antimatter as a consequence of projection processes during monopolar eversion.

10 Temporal Shield as a Necessary Condition for Safe SDG Research

Scale-Dependent Geometrodynamics, as a fundamental theoretical concept affecting the basic structures of spacetime, opens unprecedented opportunities for scientific cognition and technological development. However, the fundamental nature of this research field generates potential risks whose scale cannot be overestimated. Any experimental intervention in the structure of three-component time, manipulation of basic interactions, or modification of projection operators between different scale levels can have unpredictable consequences, up to global disruptions in the stability of the spacetime continuum.
Given these risks, it seems methodologically justified and ethically necessary to precede direct experimental research in the field of SDG with the development of specialized protective technology — a temporal shield. The temporal shield represents a complex

system integrating technological, scientific, organizational, and ethical components, designed to localize and control effects associated with experimental intervention in fundamental aspects of spacetime.

Conceptually, a temporal shield $\mathcal{T}$ is based on the principles of SDG and can be mathematically defined as a closed contour of the monopolar eversion operator:

$$\mathcal{T} = \left\{ \mathcal{X} \in \mathbb{R}^{D_{eff}(\mu)} : \nabla_\mu \mathcal{M}(\mathcal{X}) \cdot \mathbf{n} = 0 \wedge \|\vec{\tau}'(x,\mu) - \vec{\tau}_0(x,\mu)\| \leq \Delta(\mu) \right\} \tag{58}$$

where $\mathcal{T}$ represents the boundary of the temporal shield, $\mathcal{M}$ is the monopolar eversion operator, $\mathbf{n}$ is the normal to the temporal contour boundary, $\vec{\tau}'$ are modified parameters of the three-component time, and $\Delta(\mu)$ are scale-dependent limits of safe deviations.
The effectiveness of the temporal shield is determined by balanced control of the three basic types of SDG interactions:

$$\hat{U}_S(\mu) = \alpha_T(\mu)\hat{T}_S(x,\mu) + \alpha_R(\mu)\hat{R}_S(x,\mu) + \alpha_X(\mu)\hat{X}_S(x,\mu) \tag{59}$$

where $\hat{T}_S$, $\hat{R}_S$, and $\hat{X}_S$ are modified operators of basic interactions, adapted for temporal shield functioning.

To enhance the practical feasibility of protective technologies within SDG, the concept of a flickering temporal shield (FT-shield) is proposed. Unlike a static temporal shield, where parameters of three-component time are maintained at fixed modified values, the FT-shield uses controlled periodic oscillations of these parameters, which allows achieving a significant increase in energy efficiency.
This concept is described in more detail in a separate work by the author, which is being prepared for publication.

11 Experimental Predictions of SDG

One of the key criteria for the scientific validity of any theory is its ability to make testable predictions. SDG offers a number of specific experimentally verifiable predictions, some of which can be tested using existing or developing technologies. Below are the main experimental predictions of the theory:

Prediction 1 (Scale-Dependent Modification of Quantum Correlations) *SDG predicts deviation from standard Bell quantum correlations with increasing distance between entangled particles. For the CHSH (Clauser-Horn-Shimony-Holt) correlation function, this is expressed as:*

$$S_{CHSH}(d) = 2\sqrt{2} \cdot [1 - \alpha \cdot (d/d_0)^\beta \cdot e^{-d/d_1}] \tag{60}$$

where $S_{CHSH}(d)$ is the CHSH parameter as a function of distance, $2\sqrt{2} \approx 2.83$ is the maximum quantum value for entangled states, $\alpha \approx 10^{-3}$ is the effect amplitude, $\beta \approx 2$ is the exponent, $d_0 \approx 10$ km is the characteristic scale of effect onset, and $d_1 \approx 100$ km is the characteristic scale of effect attenuation.

Prediction 2 (Modified Gravitational Lensing Profile) *SDG predicts specific deviations in the gravitational lensing profile associated with spatial dimensional* *reduction at galactic and cluster scales. The deflection angle of light by a gravitational lens is modified as:*

$$\alpha(\theta) = \alpha_{GR}(\theta) \cdot [1 + \Delta\alpha \cdot g(\theta/\theta_0)] \tag{61}$$

where $\alpha_{GR}(\theta)$ is the standard prediction of General Relativity, $\Delta\alpha \approx 0.05 - 0.15$ is the modification amplitude, and $g(\theta/\theta_0)$ is a function of scale dependence on angular distance θ from the lens center.

Prediction 3 (Anisotropy of Large-Scale Structure) *SDG predicts specific anisotropy in the two-point correlation function of galaxy distribution $\xi(r)$ at scales $r \gtrsim 100$ Mpc, associated with the transition from effectively three-dimensional to quasi-two-dimensional space structure. The slope of function $\gamma(r)$ in the relation $\xi(r) \propto r^{-\gamma(r)}$ changes from the standard value $\gamma \approx 1.8$ at small scales to $\gamma \approx 1.5 - 1.6$ at scales $r \approx 100 - 120$ Mpc, with subsequent return to the standard value at even larger scales.*

Prediction 4 (Modified Uncertainty Relation) *SDG predicts modification of Heisenberg's uncertainty relation at certain scales:*

$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2} \cdot [1 + \kappa \cdot \phi(\Delta x)] \tag{62}$$

where $\kappa \approx 10^{-3} - 10^{-2}$ is the modification amplitude, and $\phi(\Delta x)$ is a function dependent on position uncertainty, with maximum manifestation at mesoscopic scales.

A detailed description of experimental protocols for testing these predictions will be presented in a separate work.

12 Conclusion and Perspectives

This paper has presented a new theoretical paradigm — Scale-Dependent Geometrodynamics, offering a fundamentally different approach to understanding the structure of reality. Based on postulates about scale-dependent effective dimensionality of space, the projective nature of observable phenomena, three-component structure of time, and monopolar eversion as a mechanism for closing the structure of reality, SDG offers a unified conceptual foundation for understanding physical phenomena at all scales — from quantum to cosmological.
Key advantages of SDG include:

1. Natural explanation of dark matter and dark energy as projection effects of multidimensional geometry, without introducing new entities.
2. Geometric interpretation of quantum effects, including quantum uncertainty and entanglement, through the prism of projections of multidimensional structures.
3. New view of the origin and evolution of the Universe, regarding the Big Bang as a projection of the monopolar eversion process.
4. Unification of informational, geometric, and quantum aspects of physical reality in a single conceptual framework.

5. Explanation of the nature and values of fundamental physical constants as manifestations of the geometrodynamic structure of multidimensional reality, rather than as arbitrarily set parameters.

This work is the first in a series of papers devoted to Scale-Dependent Geometrodynamics. Subsequent publications will elaborate in detail:

1. The complete mathematical apparatus of SDG, including formalization of scale-dependent dimensionality, three-component time, information tensor, and the monopolar eversion mechanism.

2. Specific quantitative predictions of the theory that can be tested experimentally, including modifications of quantum correlations and gravitational lensing.

SDG presents a new conceptual perspective for fundamental physics, offering an integrated approach to solving some of the most complex questions facing modern theoretical physics. Although further development of the mathematical apparatus and experimental verification of the theory's predictions will require significant effort, already at this conceptual level, SDG demonstrates potential for opening new horizons in our understanding of physical reality.

12.1 Directions for Future Research

Scale-Dependent Geometrodynamics presented in this work opens a number of fundamental questions requiring further detailed investigation:

1. **Physical mechanism of scale-dependent dimensionality:** Subsequent works will examine in detail the physical mechanism enabling the change in effective dimensionality of space with scale, including the connection of this process with fundamental interactions and energetic aspects of dimensional reduction.

2. **Ontological status of three-component time:** The question of the nature of three-component time will be analyzed in detail, including the ontological status of its components (chronoangle, chronofrequency, and chronotopology) and their relation to the thermodynamic arrow of time.

3. **Geometric interpretation of monopolar eversion:** Development of a more detailed geometric interpretation of monopolar eversion is planned, using illustrative models and analogies making this concept more accessible.

4. **Emergent properties and phase transitions:** The question of transitional states of space with fractional effective dimensionality and their physical manifestations deserves special attention, including possible phase transitions during changes in scale regimes.

The author acknowledges the complexity and multi-aspectuality of these questions and plans to dedicate a series of subsequent works to them, including detailed mathematical modeling and comparison with observational data. The open nature of these questions emphasizes the potential of SDG as a developing theoretical paradigm capable of stimulating new directions in fundamental research.

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Glossary

Scale-Dependent Geometrodynamics (SDG) A theoretical paradigm offering a conceptually different approach to understanding the fundamental structure of reality, based on scale-dependent effective dimensionality of space, three-component time, and the projection mechanism of observable phenomena

Effective Dimensionality of Space ($D_{eff}(\mu)$) A function describing the dependence of the effective dimensionality of space on the scale parameter μ. The effective dimensionality exceeds 3 at microscales and becomes less than 3 at macroscales

Scale Parameter (μ) A parameter characterizing the scale of consideration of a physical system. It varies from μ_{min} (Planck scale) to μ_{max} (cosmological scale)

Dimensional Reduction The process of sequential reduction of effective dimensionality of space with increasing observation scale, including transitions 3→2, 2→1, and 1→0

Monopolar Eversion A special topological mechanism connecting the limit states of scale-dependent dimensionality and forming a closed self-referential structure of reality (uroboros)

Uroboros A closed self-referential structure of reality formed by connecting the limit states of scale-dependent dimensionality through monopolar eversion

Temporal Composite ($T(\mu) = \{\theta_t(\mu), \omega_t(\mu), \tau_t(\mu)\}$) A fundamental unified entity of time with an internal triadic structure, consisting of chronoangle (θ_t), chronofrequency (ω_t), and chronotopology (τ_t), characterizing the temporal aspects of reality at various scales

Chronoangle (θ_t) A component of the temporal composite (time), characterizing the relative orientation of the temporal flow in multidimensional space

Chronofrequency (ω_t) A component of the temporal composite (time), characterizing the rate of processes and determining the pace of system evolution

Chronotopology (τ_t) A component of the temporal composite (time), characterizing the structure of cause-effect relationships and possible paths of system evolution

Projection Mechanism A fundamental process of formation of the observable three-dimensional world through projection of structures from higher-dimensional spaces, explaining, in particular, quantum effects

Projection Operator ($\hat{P}_{n\to m}$) A mathematical operator effecting projection from n-dimensional space to m-dimensional space ($m < n$) with preservation of certain structural characteristics and with partial loss of information

T-interaction Topological coupling — a basic type of interaction related to topological aspects of the spacetime structure

R-interaction Resonance coupling — a basic type of interaction based on resonance phenomena between different scale levels

X-interaction Chronostructural field — a basic type of interaction related to the three-component structure of time (temporal composite)

Structural Differentiation ($\mathcal{S}(x, \mu)$)	A fundamental concept of SDG characterizing the primary category from which concepts of information, energy, and matter are derived
Information Tensor ($\mathcal{I}^A_B(x, \mu)$)	A tensorial characteristic of local information content at point x at scale μ, which is a key mathematical object of the information formalism of SDG
Dark Matter	In SDG, it is interpreted as a projection effect — a manifestation of higher-dimensional space geometry when projected into the three-dimensional world
Dark Energy	In SDG, it is interpreted as a manifestation of the elasticity of multidimensional space during projection curvature
Big Bang	In SDG, it is interpreted as a projection of the monopolar eversion process in multidimensional space onto the observable three-dimensional world