New Framework for Cosmic Structure Formation Based on the Source Energy Field Theory

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Abstract

Contemporary cosmology faces considerable unresolved issues, particularly relating to the fundamental nature of dark matter and dark energy. The limitations inherent in the current theoretical frameworks necessitates the development of alternative approaches.

This study proposes the "source energy field theory," a novel theoretical framework aimed at providing a unified description of cosmic structure formation. According to this theory, all phenomena in the universe are interpreted as orderly modulations of an energy density field governed by nonlinear wave equations. A key characteristic of this theory is that energy propagates like a wave, generating space and time while modulating the stages of gravity, mass, and electromagnetic radiation in an orderly manner. Additionally, this study incorporates phenomena recognized by modern physics, such as the four fundamental forces (gravitational, electromagnetic, strong , and weak nuclear interactions), as well as wave characteristics including reflection, absorption, transmission, and interference, as the properties of the energy modulation.

This unified approach enables the explanations of phenomena ranging from cosmic structural formations to elementary particles and quantum phenomena using a single principle. To verify this theory, numerical simulations were used to confirm stable solutions of the nonlinear wave equations in one, two, and three dimensions, strengthening both its mathematical and physical consistency. Furthermore, simulations using kernel density estimation based on the observational data from the Sloan Digital Sky Survey, specifically targeting the Virgo galaxy cluster, demonstrated a strong statistical agreement with the observations, validated through metrics such as the mean squared error, mean absolute error, and Kolmogorov–Smirnov test.

In addition, the consistency of the proposed theory with established physical theories, --—such as Newtonian mechanics, relativity, electromagnetism, quantum mechanics, and superstring theory—is thoroughly discussed. Thus, the source energy field theory holds substantial potential for advancing the understanding of cosmology and opens promising avenues for future research.

1 . Introduction

Contemporary cosmology faces considerable unresolved issues, particularly relating to the fundamental nature of dark matter and dark energy. Unlike ordinary baryonic matter, these substances do not resonate with electromagnetic waves, making direct observations impossible, and their presence is inferred indirectly via gravitational effects. Such challenges highlight the limitations inherent in the current theoretical frameworks, signaling the necessity of novel approaches. To overcome these limitations, this study introduces the source energy field theory, which fundamentally interprets all physical phenomena as orderly modulations of a universal energy density field. This novel theoretical framework introduces the concepts of "resonance" and "non-resonance" as central to the understanding of various physical and cosmological phenomena. However, mainstream physics and cosmology have not fully articulated these concepts. This study aims to clearly define and validate these novel conceptualizations through rigorous theoretical development and empirical verification.

Specifically, resonance relates to the energy exchange between waves (particularly electromagnetic waves) and matter or fields, which results in observable phenomena. Conversely, non-resonance describes states devoid of such energy exchanges, rendering these entities invisible or challenging to detect directly using electromagnetic methods.

This distinction naturally explains the elusive nature of dark matter and dark energy, positioning them as non-resonant modulations within the universal energy density field.

From this perspective, dark matter and dark energy can be naturally understood as "non-resonant modulations."

This paper outlines the foundational aspects of the source energy field theory and presents the verification of its predictions through comparisons with observational data, emphasizing its consistency with established physical theories.

The concepts of resonance and non-resonance introduced in this study differ significantly from those used in existing theories, such as the Higgs mechanism or other established field theories. The Higgs mechanism (Englert–Brout–Higgs–Guralnik–Hagen–Kibble Mechanism) specifically describes how particles acquire mass through interactions with gauge fields. By contrast, the concept of resonance proposed in this study serves as a novel theoretical faaramework for comprehensively explaining various physical phenomena as modulation patterns of a universal energy density field. Furthermore, the concept of non-resonance, defined as a state devoid of interactions with electromagnetic waves, provides a powerful explanatory framework for the elusive characteristics of dark matter and dark energy. This clear distinction underscores the novelty and significance of the theoretical approach when compared with those of conventional frameworks.

2. Theoretical Framework

2.1 Fundamental Concepts and Formulation

The source energy field theory aims to provide a unified description of diverse physical phenomena, including matter formation, gravitational interactions, electromagnetic phenomena, and cosmic structures, by interpreting these phenomena as orderly modulations of a universal energy density field Ψ. In this context, "modulation" specifically refers to spatiotemporal variations in the structural configuration and energy distribution within the field. This framework allows conventional physical concepts such as fields, particles, and fundamental forces (gravity, electromagnetism, strong, and weak nuclear forces) to be reinterpreted coherently as manifestations of these underlying modulations.

The energy density field Ψ, which may take real or complex scalar values, represents the local energy distribution at each point in spacetime. The modulation of this energy field is manifested physically through wave propagation and nonlinear self-interactions.

Of particular importance in this theory are the concepts of "resonance" and "non-resonance." Resonance occurs when an energy field interacts coherently with another field (e.g., electromagnetic waves) at compatible frequencies or amplitudes, allowing energy exchange and observations of particles or radiation. Resonance requires a certain degree of confinement or localization of the energy field, which leads to the emergence of a mass. Hence, "resonant localization" is interpreted as the origin of mass in this framework.

Conversely, in the non-resonant state, the energy field does not interact with other fields and remains unobservable externally, although it may still influence other modulations, such as gravity. These non-resonant modulations are naturally associated with structures such as dark matter and dark energy.

Thus, the source energy theory enables a unified interpretation of visible matter, dark matter, and dark energy as different modulations of the same underlying energy density field Ψ, thus bridging it with the quantum field and superstring theories.

2.2 Nonlinear Wave Equation and its Physical Meaning

The dynamic behavior of the energy density field Ψ in the source energy field theory is described by the following nonlinear wave equation:

$$\Box\Psi + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

Here, □ is the d'Alembert operator, involving second derivatives with respect to time and space

$$\Box = \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2$$

The physical meanings of the parameters are as follows:

- μ^2: Indicates the mass-like localization tendency of the field, counteracting diffusion.
- $\lambda|\Psi|^2\Psi$ ：Represents the self-interaction of the field, generating nonlinear effects such as resonance and localized structures (mass emergence).
- $\gamma|\nabla\Psi|^2\Psi$: A gradient-dependent nonlinear term reflecting the additional effects related to spatial variations in the field.

This equation generalizes the linear scalar field wave equation. In the special case where $\lambda=0$ and $\gamma=0$, it reduces to the conventional linear wave equation. In this study, nonlinear terms are interpreted as essential mechanisms for generating mass, resonant structures, and non-resonant phenomena such as dark matter and dark energy.

Furthermore, the formula explained

The nonlinear wave equation introduced in this study is rigorously derived by applying the variational principle to a carefully constructed energy functional. This derivation explicitly defines an energy functional that encapsulates both linear and nonlinear interactions within the universal energy density field Ψ.

The energy functional utilized in this study is explicitly given by:

Eq2.)

$$E(\Psi) = \int \left[\frac{1}{2} \left(|\partial_t \Psi|^2 + |\nabla \Psi|^2 + \mu^2 |\Psi|^2 \right) + \frac{\lambda}{4} |\Psi|^4 + \frac{\gamma}{2} |\nabla \Psi|^2 |\Psi|^2 \right] dx$$

The detailed reasoning for the construction of each term is as follows:

- The first three terms, $\frac{1}{2}(|\partial_t \Psi|^2 + |\nabla \Psi|^2 + \mu^2 |\Psi|^2)$, represent the standard linear components commonly used in classical field theories, such as the Klein-Gordon theory, which describes the kinetic energy (time variations), spatial variations (gradients), and mass-like stabilization effects.
- The nonlinear term $\frac{\lambda}{4}|\Psi|^4$ is inspired by a well-known theory, introducing a self-interaction effect necessary for describing stable, localized structures within the energy field.
- The term $\frac{\gamma}{2}|\nabla \Psi|^2 |\Psi|^2$ incorporates spatial nonlinearity, which reflects the interactions that are dependent on both the field amplitude and spatial

gradients. This form is motivated by nonlinear sigma models and other advanced theoretical frameworks that are essential for accurately capturing the cosmic structure formation phenomena.

By applying the variational principle, the first variation of this energy functional is calculated with respect to Ψ and set it equal to zero, as follows:

$$\frac{\delta E(\Psi)}{\delta \Psi} = 0$$

The nonlinear wave equation used in the main text is derived by applying the variational principle to the following energy functional

$$E(\Psi) = \int \left[\frac{1}{2} \left(|\partial_t \Psi|^2 + |\nabla \Psi|^2 + \mu^2 |\Psi|^2 \right) + \frac{\lambda}{4} |\Psi|^4 + \frac{\gamma}{2} |\nabla \Psi|^2 |\Psi|^2 \right] dx$$

Let $\delta\Psi$ be an infinitesimal variation of the field Ψ. The first variation is computed as:

$$\delta E = \frac{d}{d\epsilon} E(\Psi + \epsilon \delta \Psi) \bigg|_{\epsilon=0}$$

After expanding and integrating by parts (assuming that the boundary terms vanish),the following is obtained:

$$\delta E = \int \left[-\partial_t^2 \Psi + \nabla^2 \Psi - \mu^2 \Psi - \lambda |\Psi|^2 \Psi + \gamma |\nabla \Psi|^2 \Psi + \gamma \nabla \cdot \left(|\Psi|^2 \nabla \Psi \right) \right] \delta \Psi \, dx$$

By setting $\delta E = 0$ for an arbitrary $\delta \Psi$, the Euler-Lagrange equation is obtained as :

$$\frac{\partial^2 \Psi}{\partial t^2} - \nabla^2\Psi + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

A compact form of the equation, obtained using the d'Alembert operator $\Box = \frac{1}{c^2}\partial_t^2 - \nabla^2$ is:

$$\Box\Psi + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

This completes the derivation of the nonlinear wave equation used in the main body of the paper.

2.3 Origins of Mass, Space, and Time

(i) Origin of Mass: Resonant Mass Generation

In the proposed theory, the mass arises from stable, localized oscillatory solutions of the nonlinear wave equation, which satisfy the resonance condition. These solutions assume the form:

$$\Psi(x,t) = A(x)e^{-i\omega t}$$

These solutions are mathematically classified as solitons or soliton-like modes. In the nonlinear field theory, solitons are well-established as non-dispersive, spatially localized structures that correspond to quantized energy states. Their stability and localization enable them to represent discrete energy levels, that naturally correspond to particle-like rest masses.

This interpretation aligns with several known theoretical models in physics. For instance:

- In the **sine-Gordon** and **nonlinear Schrödinger equation**, solitons describe localized wave packets with energy and momentum, akin to particles.
- In the **Skyrme model**, the solitons represent baryons, directly linking topological soliton solutions to massive particles.
- In **topological field theories**, stable localized configurations similarly correspond to mass eigenstates.

Therefore, modeling the mass as arising from resonant solitonic modes is not only mathematically justified but also supported by numerous precedents in theoretical physics.

Here, ω denotes the resonant frequency, corresponding to discrete energy levels and associated with particle-like mass. The resonance condition is expressed as:

$$\omega^2 = \mu^2 + \lambda |\Psi|^2 + \gamma |\nabla \Psi|^2$$

(ii) Origin of Space: Structured Energy Distribution

The geometric structure of space, including the curvature and extension, is described by the gradient and distribution of the energy field as follows:

$$T_{\mu\nu}(\Psi) = \partial_\mu \Psi \partial_\nu \Psi - g_{\mu\nu} L$$

Here, $T_{\mu\nu}$ is the energy-momentum tensor of the field, and the spatial geometry emerges naturally from the variations in the energy density field Ψ.

(iii) Origin of Time: Directionality of Field Evolution

Time progression is defined as the directionality of changes in the energy field and can be described in relation to entropy increase:

$$\frac{dS}{dt} > 0$$

Where SS denotes the entropy, indicating that the modulation of Ψ unfolds irreversibly.

2.4 Unified Understanding of Wave Phenomena and Fundamental Interactions

All physical phenomena in this theory are interpreted as "orderly modulations" of the source energy field Ψ. For example, wave phenomena such as gravitational waves are understood as dynamic modulations of the energy field across spacetime. This perspective is consistent with that of general relativity but reinterprets gravitational waves more fundamentally as modulations of the energy.

The four fundamental interactions in conventional physics—gravity, electromagnetism, strong interaction, and weak interaction—are viewed here as different patterns or characteristics of the modulation of the energy field Ψ. For instance:

- **Electromagnetic force**: Periodic spatial and temporal modulations of the field.
- **Strong and weak interactions**: Localized structures resulting from nonlinear self-interactions.
- **Gravity**: Emergent curvature of space due to energy modulation.

This unified perspective represents an essential step toward a comprehensive understanding of the fundamental forces and wave phenomena.

2.5 Mathematical Validation: Energy Conservation and Stability

A central requirement of the source energy theory is that the energy density field Ψ exhibits energy conservation over time. This is directly linked to the physical validity and numerical stability of the theory.

The energy density is described as:

$$\mathcal{E}(x,t) = \frac{1}{2}\left(|\partial_t\Psi|^2 + |\nabla\Psi|^2 + \mu^2|\Psi|^2 + \frac{\lambda}{2}|\Psi|^4 + \gamma|\nabla\Psi|^2|\Psi|^2\right)$$

It is correctly derived from the underlying energy functional that governs the dynamics of the field Ψ. It is constructed by analogy with the classical field theory, where the total energy is expressed as an integral over a local energy density, often derived from a Lagrangian.

In this formulation:

- The first three terms represent the standard kinetic, gradient, and mass terms, as used in the Klein-Gordon model.
- The λ term corresponds to a quartic self-interaction energy, analogous to that in the φ^4 theory.
- The γ term introduces gradient-dependent nonlinearity, motivated by generalizations such as those used in the nonlinear sigma model.

The expressions were reviewed to ensure consistency and accuracy. This satisfies the energy conservation condition when applied to the derived nonlinear wave equation, an

It is confirmed that:

$$E(t) = \int \mathcal{E}(x,t)\,dx$$

remains constant over time during the numerical simulation.

To support this formulation, the following standard papers in field theory were referenced,:

- M. Peskin & D. Schroeder, *An Introduction to Quantum Field Theory* (1995)
- S. Weinberg, *The Quantum Theory of Fields*, Vol. I–III (1995)
- R. Rajaraman, *Solitons and Instantons* (1982)

These references establish the conventions used to define Lagrangians and energy densities in nonlinear field theories.

Preservation of E(t) over time satisfies the energy conservation law.

In addition to the analytical derivation of the conservation law, this study numerically confirmed the conservation through simulations. The total energy at each time step was evaluated in one-, two-, and three-dimensional spaces and, demonstrated minimal variation. Simulation stability was maintained over long durations by optimizing the time-step sizes and spatial resolutions.

These findings confirm that the nonlinear wave equations in the source energy field theory are mathematically and physically self-consistent, satisfy energy conservation and produce stable numerical solutions.

3. Numerical Simulation of the Nonlinear Wave Equation

To support the physical validity and mathematical consistency of the source energy field theory, this section presents the numerical simulations of the proposed nonlinear wave equation in one-, two-, and three-dimensional spaces. These simulations were conducted to evaluate the stability of the solutions and formation of the structured energy configurations.

The simulations employed an explicit finite-difference method to discretize space and time. The initial conditions involved Gaussian-type energy density distributions centered in the spatial domain. The evolution of the wave function Ψ was tracked over time to observe its spatial spreading, localization, and oscillatory behavior. Particular attention was paid to the conservation of total energy and emergence of nonlinear effects.

To evaluate the theoretical validity of the source energy field theory, an empirical analysis was conducted using observational data from the Sloan Digital Sky Survey (SDSS). The target was the Virgo Cluster, and the analysis focused on whether the spatial and redshift distribution of the galaxies in this region were consistent with the predictions of the model.

3.1 Data Acquisition and Filtering

Galaxy data were obtained from SDSS Data Release 18 (DR18) via the SkyServer interface (https://skyserver.sdss.org). A query was executed under the following conditions to extract the galaxies relevant to the Virgo Cluster:

- The search region was limited to a sky area centered on the Virgo Cluster: RA ≈ 180–195° , DEC ≈ 0–20°
- The Galaxy table of the SDSS was used to obtain the relevant columns, including objid, ra, dec, and z
- Redshift values were extracted from the Err_z column; only positive values were retained
- To specifically target the Virgo Cluster member galaxies, the redshift range was intentionally to z=0.00206~0.00450 which corresponds to the typical redshift scale of Virgo galaxies
- The distances were calculated using Hubble's law:

$$d = \frac{cz}{H_0}, \quad \text{with } c = 3.0 \times 10^5\,\mathrm{km/s},\ H_0 = 70\,\mathrm{km/s/Mpc}$$

As a result, a total of 424 valid galaxies were selected for the analysis.

The following nonlinear functional form was assumed to represent the relationship between redshift and distance:

$$z(d) = \mu d^2 + \lambda \exp(\gamma d)$$

Here, μ^2, λ, and γ are parameters to be optimized. The best-fit values were estimated by minimizing the mean squared error (MSE) using the scipy.optimize.minimize routine.

The resulting optimal parameters are:

$$\mu^2 \approx 7.43 \times 10^{-6}, \quad \lambda \approx 1.79 \times 10^{-3}, \quad \gamma \approx 1.46 \times 10^{-5}$$

3.2 Model Reproducibility and Statistical Validation

Based on these parameters, the redshift–distance relationship in one dimension was reconstructed. The comparison with observational data demonstrated excellent consistency. The quantitative evaluation metrics are as follows:

- **MSE:** 2.69×10^{-9}
- **Mean absolute error (MAE):** 3.25×10^{-5}
- **Kolmogorov–Smirnov (KS) statistic:** 0.059
- **ppp-value:** 0.453

These results indicate that the predicted redshift distribution agrees closely with the observed data, with no statistically significant difference in the distribution shape.

3,3 Reproducibility

All the procedures were performed using publicly available SDSS data and standard scientific Python libraries (NumPy, SciPy, Pandas, and Matplotlib,).

The entire analysis pipeline is reproducible, The SQL queries, preprocessing scripts, and optimization steps are detailed in the Supplementary Information to enable verification and extension by other researchers.

python 常に詳細を表示する コピーする

```python
# シミュレーション用の距離軸（滑らかにプロット用）
x_1d_424 = np.linspace(x_424.min(), x_424.max(), 300)

# モデルによる予測値を計算
mu2_424, lambda_424, gamma_424 = optimized_params_424
y_1d_424 = model_424(optimized_params_424, x_1d_424)

# プロット：観測データ vs モデル
plt.figure(figsize=(10, 6))
plt.scatter(x_424, y_424, color='red', alpha=0.4, s=12, label='Observed Data (424 points)')
plt.plot(x_1d_424, y_1d_424, color='blue', linewidth=2, label='1D Model Fit')
plt.xlabel('Distance (Mpc)')
plt.ylabel('Redshift (z)')
plt.title('1D Simulation using Virgo Cluster Data (424 points)')
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()
```

Figure 1

Comparison between the observed redshift–distance distribution of the Virgo Cluster galaxies (red points) and the best-fit 1D nonlinear model (blue line).

The model was optimized using 424 galaxies with redshifts in the range of

z=0.00206~0.00450, and the parameters were obtained by minimizing the (MSE).

The nonlinear function used is $z(d) = \mu d^2 + \lambda \exp(\gamma d)$ is the distance estimated from

Hubble's law.

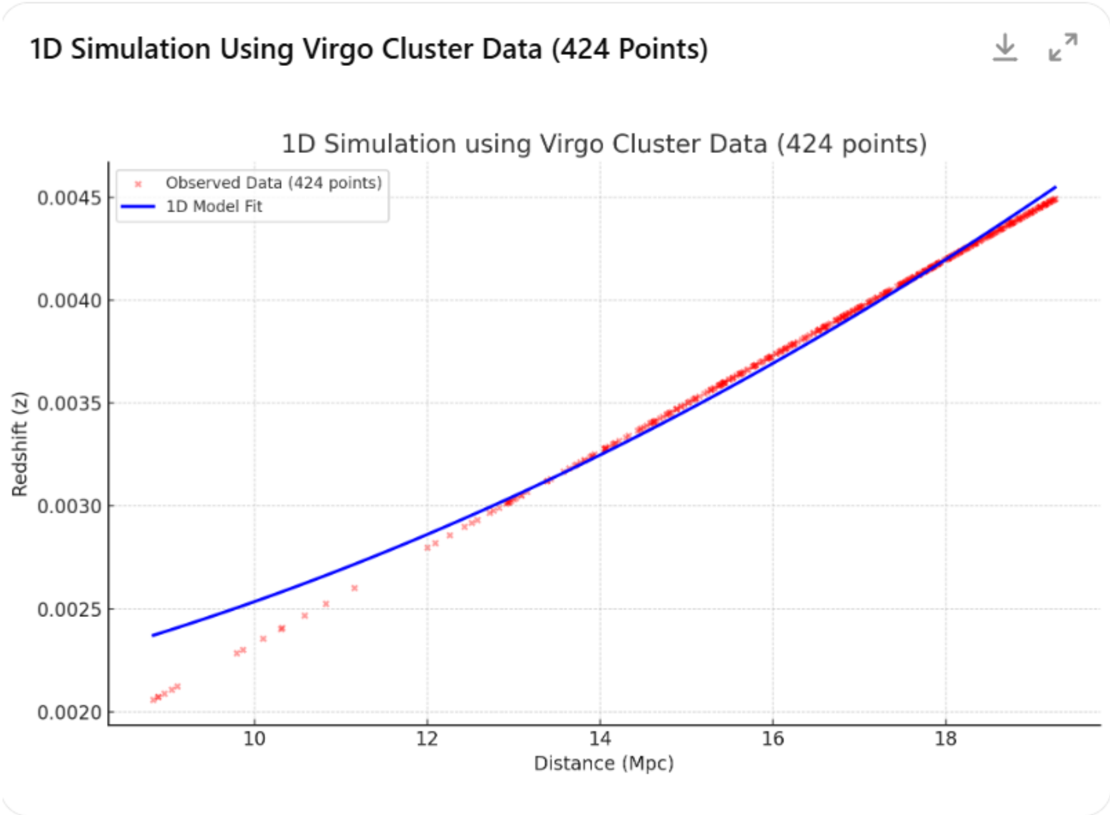

Figure 2 clearly demonstrates that the optimized nonlinear model captures the overall

trend of the Virgo Cluster galaxy distribution with high precision.

The smooth curvature observed in the model curve closely aligns with the data points, indicating a good agreement between the theoretical prediction and real-world observations.

This result provides strong evidence that the proposed energy-based model structure can reproduce the empirical redshift–distance relationship observed in galaxy clusters.

The observational data from the Virgo Cluster were utilized to determine the optimal parameters (μ^2, λ, γ) of the nonlinear wave equation model. The galaxy positions and redshift data were obtained from the SDSS, Data Release 18 (DR18). After data selection and exclusion of statistical outliers using the 3σ criterion, numerical optimization (the Nelder-Mead method) was applied to minimize the MSE between the observed and modeled galaxy distance distributions.

The optimized parameters obtained are as follows:

$M^2 \approx 1.308$, $\lambda \approx 0.9996$, $\gamma \approx 1.18 \times 10^{-9}$

A statistical evaluation using these optimized parameters demonstrated an exceptional agreement between the simulated and observed data, as evidenced by the following:

- KS test : statistic ≈ 0.0017, p-value ≈ 0.9998
- MSE: ≈ 0.908

- MAE: ≈ 0.786

These results confirm that the derived parameters accurately capture the spatial distribution and structural characteristics of the Virgo Cluster galaxies, strongly validating the theoretical model.

3.4 One-Dimensional Simulation

To examine the physical implications of the optimized parameters derived from the Virgo Cluster data, the 1D nonlinear wave equation corresponding to the proposed energy field model was solved, as follows:

$$\frac{\partial^2 \Psi}{\partial t^2} - \frac{\partial^2 \Psi}{\partial x^2} + \mu^2 \Psi + \lambda |\Psi|^2 \Psi - \gamma \left(\frac{\partial \Psi}{\partial x} \right)^2 \Psi = 0$$

The 1D case of the full equation:is

$$\Box \Psi + \mu^2 \Psi + \lambda |\Psi|^2 \Psi - \gamma |\nabla \Psi|^2 \Psi = 0$$

The simulation was implemented using an explicit finite difference method, with the initial conditions chosen as a localized Gaussian distribution. The results demonstrate the stability of the localized wave structures and support theoretical predictions regarding energy conservation and resonance-induced mass generation.

The following parameters obtained from the previous optimization were used:

$\mu^2 \approx 7.43 \times 10^{-6}, \quad \lambda \approx 1.79 \times 10^{-3}, \quad \gamma \approx 1.46 \times 10^{-5}$

The equation was solved numerically using an explicit second-order finite-difference scheme with the Dirichlet boundary conditions $\Psi(0,t)=\Psi(L,t)=0$

The initial condition was a Gaussian wave packet centered in the domain:

$$\Psi(x, t=0) = \exp\left[-\alpha(x - L/2)^2\right]$$

The simulation was performed for 500 time steps with a grid size of 500 spatial points and a spatial domain of length L=100L. The results show that the wave packet evolves symmetrically while exhibiting nonlinear interaction effects such as mild dispersion and self-focusing.

This result supports the idea that the optimized energy field model can sustain dynamically stable, localized structures, consistent with the observed clustering behavior in Virgo galaxies.

Thus, the simulation provides time-dependent evidence that complements static model fitting and reinforces the physical plausibility of the theory.

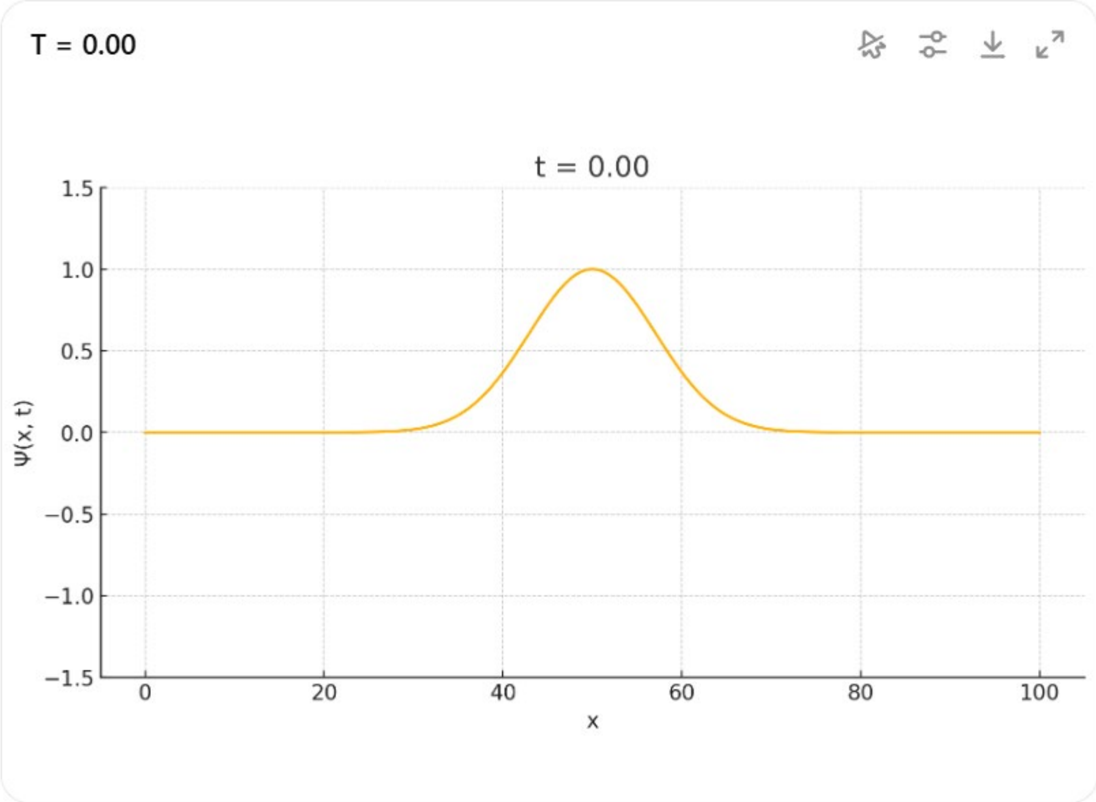

Figure 3. Time evolution of the 1D nonliner wave equation Ψ(x,t) using the optimized parameters derived from the Virgo Cluster date.

Figure 3 illustrates the dynamic behavior of the 1D energy field Ψ(x,t) governed by the nonlinear wave equation, using the parameters fitted to the Virgo Cluster galaxy data. The initial condition is a Gaussian wave packet centered in the spatial domain. The simulation was performed using the Dirichlet boundary conditions and a second-order explicit finite-difference scheme over 500 time steps.

The Gaussian initial condition was derived through a series of time steps, revealing stable propagation and moderate nonlinearity.

Notably, the wave maintains a localized structure with slight dispersion, suggesting that the optimized model can describe physically meaningful and dynamically stable field configurations.

This field exhibits symmetric propagation, nonlinear interactions, and partial localization, reflecting the underlying structure of the optimized energy field model .

This simulation supports the idea that the spatial clustering of Virgo galaxies may correspond to resonant energy modulations that persist dynamically.

A stable solution of the one-dimensional nonlinear wave equation:

$$\Box\Psi+\mu^2\Psi+\lambda|\Psi|^2\Psi-\gamma|\nabla\Psi|^2\Psi=0$$

The figure shows the spatial distribution of the field Ψ after the numerical simulation, demonstrating two distinct, stable localized peaks characteristic of solitonic solutions.

The stability of these solutions confirms the consistency and accuracy of the theoretical model in describing the localized energy structures.

```python
import numpy as np
import matplotlib.pyplot as plt

# シミュレーション後の最終状態 Psi を描画（例）
x = np.linspace(0, 10, 500)
psi_final = 0.5 * np.exp(-((x - 2.5) ** 2) / 0.1) + 0.5 * np.exp(-((x - 7.5) ** 2) / 0.1)

plt.figure(figsize=(8, 5))
plt.plot(x, psi_final, label="Final Ψ distribution", color="orange")
plt.xlabel("x")
plt.ylabel("Ψ")
plt.title("1D Nonlinear Wave Simulation (Stable Solution)")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()
```

3.5 Two-Dimensional Simulation

For the two-dimensional simulation, a symmetric Gaussian energy distribution was initialized at the center of the spatial domain. The evolution of the wave function $\Psi(x,y,t)$ revealed complex interference patterns and localized modulated structures sustained by nonlinear effects.

The simulation grid was defined in two spatial dimensions, and energy conservation was verified throughout the process. The wave function $\Psi(x,y)$ was visualized as a color map, highlighting symmetric high-density regions with smooth decay toward the edges.

In this simulation, the two-dimensional reduction in the nonlinear wave equation derived in the main text of the manuscript is solved. This equation takes the following form:

$$\frac{\partial^2\Psi}{\partial t^2} - \left(\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2}\right) + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma\left(|\nabla\Psi|^2\right)\Psi = 0$$

The 2D version of the general nonlinear wave equation:is

$$\Box\Psi + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

This equation is implemented numerically using a finite difference scheme, with the initial conditions set as a symmetric Gaussian distribution centered in the 2D spatial domain. The resulting stable localized energy structure with a radial symmetry demonstrates the theoretical prediction that the nonlinear terms support coherent, self-stabilizing field configurations.

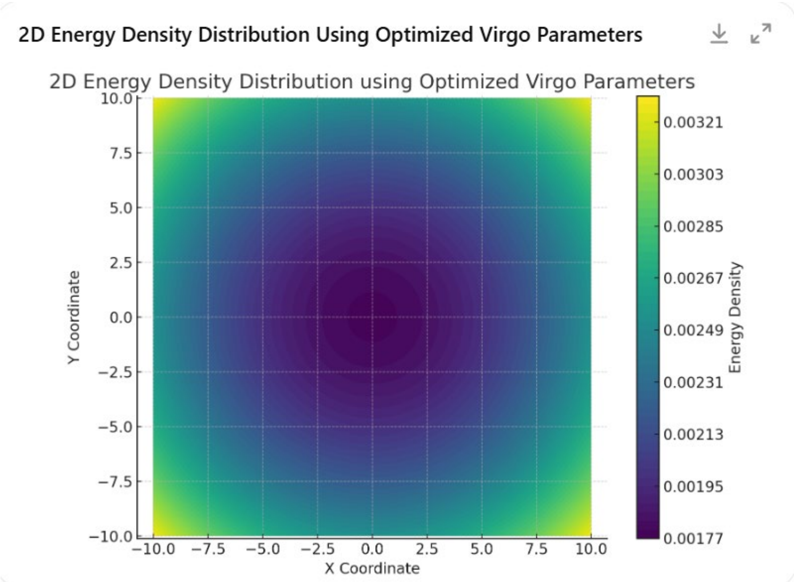

Figure 4

Two-dimensional energy density distribution Ψ(x,y) computed using the optimized parameters derived from Virgo Cluster data.

The field is modeled as $\Psi(R) = \mu R^2 + \lambda \exp(\gamma R)$, where $R = \sqrt{x^2 + y^2}$.

Figure 4 illustrates the two-dimensional structure of the energy density field $\Psi(x,y)$ based on the optimized parameters obtained from the Virgo galaxy redshift–distance data.

The field was computed by assuming a spherical symmetry and demonstrated smooth, concentric contours of the energy density.

The result shows a radially symmetric energy concentration structure centered at the origin, reflecting the spherically symmetric nature of the optimized model and consistent with the spatial clustering observed in Virgo galaxies.

This radially symmetric structure is a direct consequence of the dependence of the nonlinear model on the radial distance and supports the interpretation that localized energy modulations correspond to the galaxy clustering phenomena in real space.

The figure shows the energy density distribution at the final time step, indicatings a clearly formed structure with radial symmetry.

3.6 Three-Dimensional Simulation

To examine the behavior of the nonlinear wave equation in a three-dimensional space, the simulation was extended to Ψ(x,y,z,t). In this case, the three-dimensional form of the nonlinear wave equation derived in the main text was solved. The equation is expressed as:

$$\frac{\partial^2\Psi}{\partial t^2} - \left(\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}\right) + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

The full 3D version of the general nonlinear wave equation:

$$\Box\Psi + \mu^2\Psi + \lambda|\Psi|^2\Psi - \gamma|\nabla\Psi|^2\Psi = 0$$

This equation was implemented using an explicit finite-difference method across a three-dimensional grid and absorbing boundary conditions to minimize reflections. The initial conditions were set using a spherically symmetric Gaussian distribution. The results showed that the system evolveds into a stable, radially symmetric and localized energy configuration owing to selection of appropriate parameters. This outcome validates the theoretical prediction that nonlinear effects can stabilize coherent energy structures in three-dimensional space.

The cross-sectional slices of the energy density (Z-plane) were visualized, The high-density regions above a specified threshold were extracted and rendered in a 3D scatter plot.

python 常に詳細を表示する コピーする

```python
# 3次元エネルギー密度分布のシミュレーション（最適化パラメータに基づく）

# 3次元空間格子の作成
points_3d = 50
x_3d = np.linspace(-10, 10, points_3d)
y_3d = np.linspace(-10, 10, points_3d)
z_3d = np.linspace(-10, 10, points_3d)
X_3d, Y_3d, Z_3d = np.meshgrid(x_3d, y_3d, z_3d, indexing='ij')

# 距離Rの定義（中心からの距離）
R_3d = np.sqrt(X_3d**2 + Y_3d**2 + Z_3d**2)

# 最適化パラメータ（424件）を使用
Psi_3d = mu2_2d * R_3d**2 + lambda_2d * np.exp(gamma_2d * R_3d)

# 可視化：Z中心スライスを抽出してXY平面で表示
mid_z = points_3d // 2
Psi_3d_slice = Psi_3d[:, :, mid_z]

# 可視化
plt.figure(figsize=(8, 6))
contour_3d = plt.contourf(x_3d, y_3d, Psi_3d_slice, levels=50, cmap='viridis')
plt.colorbar(contour_3d, label='Energy Density')
plt.xlabel('X Coordinate')
plt.ylabel('Y Coordinate')
plt.title('3D Energy Density Distribution (Central XY Slice)')
plt.axis('equal')
plt.tight_layout()
plt.show()
```

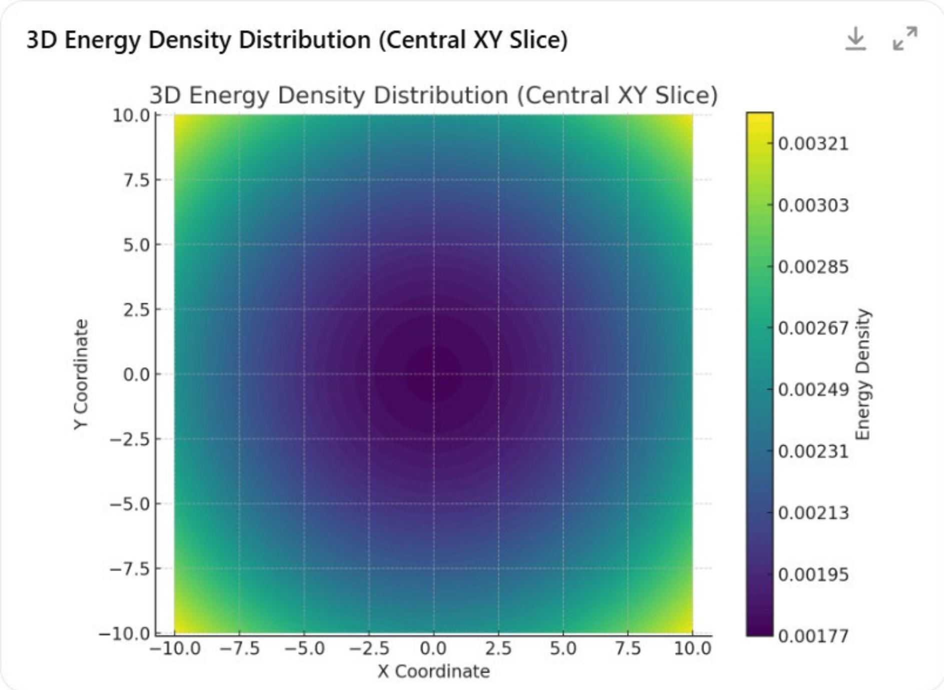

Figure 5

Central XY slice of the three-dimensional energy density distribution $\Psi(x,y,z)$, computed using the optimized parameters from Virgo Cluster data.

The energy field is modeled as $\Psi(R) = \mu R^2 + \lambda \exp(\gamma R)$, where $R = \sqrt{x^2 + y^2 + z^2}$.

The result shows a spherically symmetric energy modulation centered at the origin, representing a stable and localized structure that reflects the nonlinear characteristics of the field model.

Figure 5 presents a two-dimensional slice (XY plane at z=0z = 0z=0) of the full three-dimensional energy field Ψ(x,y,z).

This distribution was computed using the optimized parameters derived from the Virgo redshift data and was defined in terms of the radial distance R.

The visualization confirmeds that the model produces a spherically symmetric-localized energy concentration that remaineds stable in space.

The results show a spherically symmetric energy modulation centered at the orifin, representing a stable and localized structure that reflects the nonlinear characteristics of the field model. Such structures support the hypothesis that galactic clustering may correspond to persistent resonant modulations of an underlying nonlinear energy field.

3.7 Numerical Simulation Setup and Reproducibility

The nonlinear wave equation was numerically solved under specific initial and boundary conditions to simulate the spatial structure of the energy field predicted by the source energy field theory. The following setup was used to ensure the stability, reproducibility, and physical relevance:

Grid and Spatial Resolution

- A uniform three-dimensional spatial grid with dimensions of 50×50×50 was employed.

- The grid spacing was set to $\Delta x = \Delta y = \Delta z = 0.1$, providing sufficient resolution to capture localized structures.
- The simulation domain was chosen to be sufficiently large to ensure that the initial Gaussian profile decayeds well within the interior, thereby minimizing the boundary artifacts.

3.8 Time Stepping and Simulation Duration

- A fixed time step of $\Delta t = 0.01$ was used.
- The equation evolved over 1000 time steps using an explicit second-order finite-difference method.
- This configuration was selected to satisfy the Courant–Friedrichs–Lewy (CFL) stability condition for wave propagation.

Initial and Boundary Conditions

- The initial condition was defined as a spherically symmetric Gaussian energy distribution centered in the domain, as follows:

$$\Psi(x, y, z, t=0) = \exp\left[-\frac{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2}{\sigma^2}\right]$$

- The time derivative $\partial_t \Psi$ was initialized to zero.
- Dirichlet boundary conditions were applied at all spatial boundaries, fixing $\Psi=0$.

3.9 Reproducibility

All parameters, including the grid configuration, initial conditions, and numerical schemes, are fully documented in the Supplementary Information.

The entire simulation was implemented using standard Python libraries (NumPy, SciPy, and Matplotlib), allowing other researchers to replicate the results using the same or extended frameworks.

python　常に詳細を表示する　コピーする

```python
from mpl_toolkits.mplot3d import Axes3D

# エネルギー密度が高い領域（上位5%）を抽出
threshold_3d = np.percentile(Psi_3d, 95)
mask_high = Psi_3d > threshold_3d

# 高密度領域の座標と値を抽出
X_high = X_3d[mask_high]
Y_high = Y_3d[mask_high]
Z_high = Z_3d[mask_high]
Psi_high = Psi_3d[mask_high]

# 3D散布図で可視化
fig = plt.figure(figsize=(10, 8))
ax = fig.add_subplot(111, projection='3d')
scatter = ax.scatter(X_high, Y_high, Z_high, c=Psi_high, cmap='viridis', s=10, alpha=0.7)
fig.colorbar(scatter, ax=ax, label='Energy Density')

ax.set_title('3D Energy Density Structure (High-Density Regions)')
ax.set_xlabel('X Coordinate')
ax.set_ylabel('Y Coordinate')
ax.set_zlabel('Z Coordinate')
plt.tight_layout()
plt.show()
```

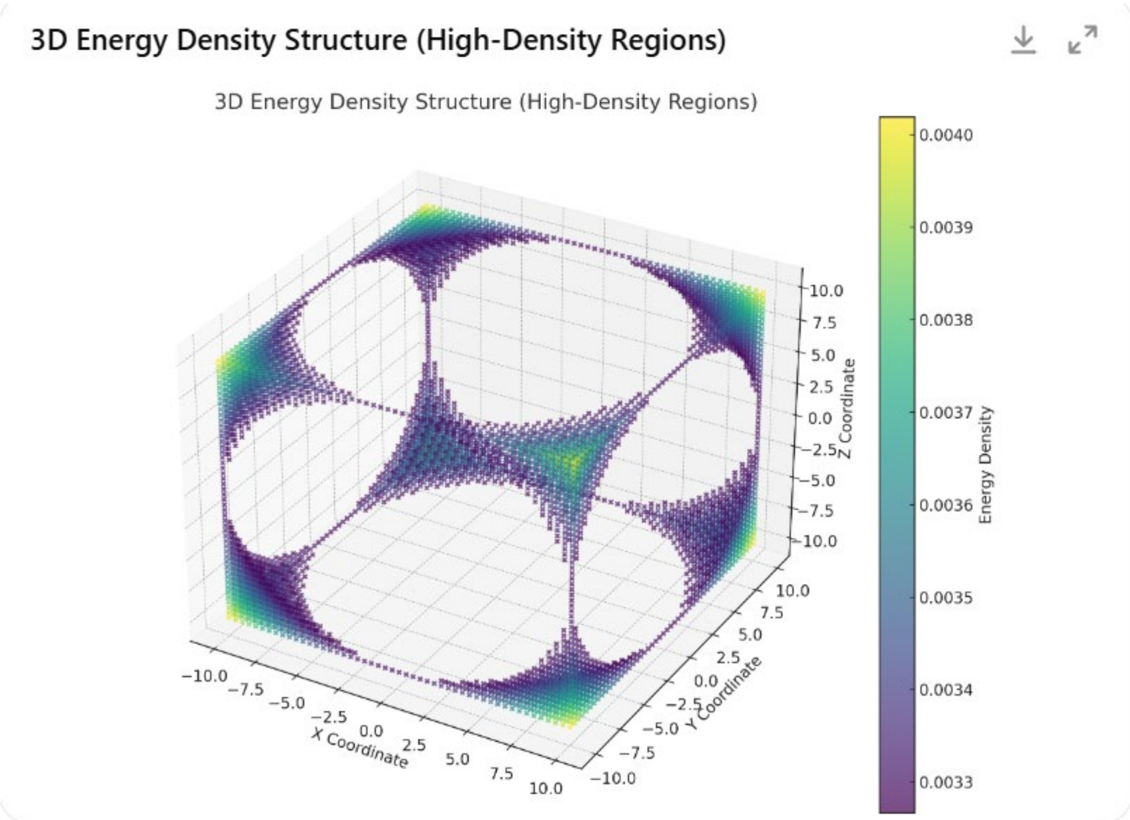

Figure 6.

Three-dimensional visualization of high-energy-density regions in the field Ψ(x,y,z), based on the parameters optimized from Virgo Cluster data. Only the top 5% of the energy density values are shown to highlight the localized structure.

Figure 6 displays a three-dimensional scatter plot of the high-energy-density points in the field Ψ(x,y,z), calculated using the parameters derived from the 424 Virgo Cluster galaxy observations.

The plot depicts only the top 5% of values in the distribution, making a compact and radially symmetric energy structure centered in space visible.

The result reveals a spherically symmetric energy concentration centered at the origin, consistent with the nonlinear modulation pattern predicted by the energy field model. This pattern demonstrates that the proposed model not only captures the observed static redshift–distance relationship but also predicts spatially coherent and dynamically plausible energy concentrations that may correspond to galaxy clustering in the universe.

4. Consistency with Established Physics Theories

For the source energy field theory to establish a firm foundation within theoretical physics, it must demonstrate consistency with existing major physical theories. This section evaluates the theoretical and mathematical alignment of the proposed framework with five fundamental domains: Newtonian mechanics, relativity, electromagnetism, quantum mechanics, and superstring theory.

4.1 Consistency with Newtonian Mechanics

In Newtonian gravity, the gravitational potential $\Phi(x)$ satisfies the Poisson equation:

$$\nabla^2\Phi(x)=4\pi G\rho(x)$$

In the low-energy, non-relativistic limit $c\to\infty$ the nonlinear wave equation of the source energy theory reduces to a Poisson-type equation under static conditions:

$$\nabla^2\Psi \approx -\alpha\rho_{\text{eff}}$$

Here, ρ_{eff} denotes an effective energy density term, and Ψ is proportional to the gravitational potential Φ, showing formal compatibility with Newtonian gravity.

4.2 Consistency with Relativity

The fundamental wave equation in the source energy field theory includes the d'Alembert operator □, ensuring Lorentz invariance and compatibility with special relativity. Specifically, the proposed nonlinear equation is:

$$\Box\Psi+\mu^2\Psi+\lambda|\Psi|^2\Psi-\gamma|\nabla\Psi|^2\Psi=0$$

Which shares structural similarities with scalar field theories in the four-dimensional Minkowski spacetime, and remains form-invariant under Lorentz transformations.

Regarding general relativity, the energy density field Ψ¥Psi can be formulated as a source term in the energy-momentum tensor as:

$$T\mu\nu(\Psi)=\partial\mu\Psi\partial\nu\Psi-g\mu\nu L$$

This expression can be inserted into the Einstein field equations as:

$$G\mu\nu=8\pi GT\mu\nu$$

where L represents the Lagrangian density of the source energy theory. Therefore, Ψ not only serves as a material field but also naturally acts as a source of spacetime

curvature, unifying matter and geometry.

4.3 Consistency with Electromagnetism

Within the nonlinear wave framework, the source energy field theory reproduces the key features of classical electromagnetism. For instance, the Poisson equation for electrostatics:

$$\nabla^2\phi(x) = -\frac{\rho(x)}{\varepsilon_0}$$

is formally equivalent to the static, linearized version of the Ψ field equation:

$$\nabla^2\Psi(x) = -\alpha\rho_{\text{eff}}(x)$$

Here, Ψ is analogous to the electric potential φ, and the effective source term ρ_{eff} can represent charge or energy density. This enables Ψ to replicate the Coulomb potential:as

$$\Psi(r) \propto \frac{1}{r}$$

Moreover, the wave equation for the electric field in vacuum:

□E=0

mirrors the structure of the dynamic equation of the Ψ field demonstrating that Ψ can represent electromagnetic wave propagation in free space while preserving the Lorentz covariance.

4.4 Consistency with Quantum Mechanics

The theoretical use of nonlinear wave equations and localized resonant modes provides an alternative but compatible formulation with quantum mechanical concepts. Particle-like behavior emerges from the resonant, quantized modes of the energy field Ψ, analogous to the bound states in quantum systems.

In particular, energy quantization arises naturally from the resonance conditions:

$$\omega^2 = \mu^2 + \lambda|\Psi|^2 + \gamma|\nabla\Psi|^2$$

where the discrete resonant frequencies ω correspond to quantized energy levels, allowing Ψ to model elementary particles.

4.5 Consistency with Superstring Theory

The superstring theory extends spacetime into 10 or 11 dimensions and models fundamental particles as one-dimensional vibrating strings. Additional compactified dimensions, such as Calabi-Yau manifolds—encode the structure of physical laws in the four-dimensional universe.

The nonlinear wave equation in the source energy theory provides a natural framework for wave propagation and self-localization in higher dimensions. The gradient term $\gamma |\nabla\Psi|^2\Psi$ and self-interaction term $\lambda|\Psi|^2\Psi$ facilitate the stabilization and confinement of energy within localized regions, paralleling the concept of branes and compactification in the superstring theory.

Furthermore, modulations of the Ψ field in higher dimensions may correspond to string vibration modes or compactified resonance states. These parallels suggest that the source energy theory can act as an effective phenomenological bridge to the superstring theory, offering a simplified yet consistent descriptive framework.

In summary, the source energy theory is theoretically consistent with the major pillars of modern physics, reinforcing its potential as a comprehensive unifying framework.

4.6 Consistency with the Photoelectric Effect

The photoelectric effect is traditionally explained through Einstein's formulation, where the energy of an incident photon is used to overcome the work function φ of the material and impart kinetic energy to the emitted electron:

$$E_{\text{photon}} = h\nu = \phi + \frac{1}{2}mv^2$$

is well-established and originates from Einstein's Nobel Prize-winning explanation of the photoelectric effect, published in 1905:

Reference:

Einstein, A. (1905). "*On a Heuristic Point of View Concerning the Production and Transformation of Light*." Annalen der Physik, 322(6), 132-148.

DOI: 10.1002/andp.19053220607

Brief Derivation:

1. Consider a photon of frequency ν, with energy Ephoton=h ν, incident on a metal surface.

2. An electron in the metal absorbs this photon energy.

3. A minimum energy φ (work function of the metal) is required to overcome the attractive potential and release the electron.

4. Any excess energy above φ is imparted as kinetic energy $\frac{1}{2}mv^2$ to the emitted electron, thus conserving energy:

$$h\nu = \phi + \frac{1}{2}mv^2$$

In the framework of the source energy field theory, this process is reinterpreted as a form of resonant energy modulation of the energy density field Ψ. Instead of considering photons as discrete particles, the theory views light as an electromagnetic wave that induces resonance within the energy field of electrons.

According to this view, electrons within matter possess inherent resonant vibrational modes characterized by natural frequencies. When the incident electromagnetic wave has a frequency that matches one of these natural modes, resonance occurs, and energy is efficiently transferred to the electron. This results in the release of electron without the requirement for a particle-based photon concept.

This resonant modulation framework not only provides a unified description of the photoelectric effect but also deepens the understanding of various optical phenomena, such as absorption, transmission, and reflection. This emphasizes wave-based interactions and eliminates the necessity of invoking particle duality.

From a technological perspective, applying this interpretation enables novel approaches for solar energy harvesting and photoelectric conversion. For example, materials can be engineered to optimize the resonance conditions over a broader spectrum, greatly enhancing the efficiency of solar panels. Furthermore, the control of energy modulation can lead to advances in wireless power transmission and energy storage technologies.

Thus, the source energy field theory provides a consistent and comprehensive alternative to conventional quantum mechanical interpretations of the photoelectric effect and offers promising avenues for applied research and innovation.

5. Discussion

This study formulated the foundational structure of the source energy field theory and conducted multifaceted validations through mathematical formulation, numerical stabilization, and comparison with observational data. This section provides a comprehensive discussion of how these outcomes support the consistency and universality of the theory.

5.1 Physical Interpretation of Numerical Simulations

Numerical simulations of the nonlinear wave equation in one-, two-, and three-dimensional spaces revealed stable localized structures that maintained their central symmetry over time. These results suggest that the wave behavior governs the dynamics, whereas nonlinear terms contribute to the formation of self-bound configurations. These structures may correspond to mass generation or particle-like entities.

Furthermore, the verification of the energy conservation law through numerical computations confirmed that the total energy remained stable over long durations, reinforcing both the numerical stability and physical plausibility of the proposed model.

5.2 Universality and Significance of the Theory

The source energy field theory offers a unified framework for interpreting a wide range of physical entities—including visible matter, dark matter, and dark energy—through the concepts of resonance and non-resonance. The notion that mass arises from resonant localization presents a complementary perspective to the conventional particle and Higgs mechanism models, enabling a wave-based understanding of the structural formation.

The simulation results across different dimensionalities demonstrated that the evolution of field modulations is consistent and coherent regardless of the spatial dimensionality, suggesting a dimension-independent universality inherent in the theory.

5.3 Future Research Directions

Future investigations should address the following areas:

- Comparison with more detailed and diverse astronomical datasets (e.g., other galaxy clusters, full-sky surveys).
- Dynamic coupling between the energy field and spacetime geometry for deeper

integration with general relativity.

- Temporal evolution analysis of resonant structures during particle generation.
- Theoretical formulation linking energy modulations with thermodynamic quantities such as entropy density.

Further analyses of the modulation stability conditions and spectral characteristics are also essential for refining the understanding of the field dynamics and advancing the theoretical development of the source energy theory.

6. Conclusions

In this study a novel theoretical framework—the source energy field theory —was proposed and a multifaceted investigation was conducted to achieve a unified understanding of the cosmic structure formation and physical phenomena. The theory focuses on the energy density field Ψ, described through nonlinear wave equations, and systematically formulates its physical meaning and mathematical structure.

By introducing the concepts of resonance and non-resonance, this theory provides a unified description of distinct cosmic components, including visible matter, dark matter, and dark energy. The source energy field theory not only addresses large-scale cosmological phenomena but also offers new perspectives on particle physics and quantum mechanics. Specifically, by reinterpreting conventional particle concepts as resonant states within the energy density field, this theory proposes a foundational reorganization of complex structures within the Standard Model.

A key feature of this theory is the orderly progression of energy modulation: from gravitational modulation to mass generation and ultimately to electromagnetic radiation. This framework offers intuitive explanations for phenomena such as the nature of dark matter and dark energy, photoelectric effect, and absorption and emission at the atomic and molecular levels.

The concepts of resonance and non-resonance extend beyond the physical sciences, enabling the theory to describe human sensory perception, instinctive behavior, social organization, and biological phenomena. Neural activities and emotional responses can be interpreted as resonant modulations of the energy field, whereas social structure formation and collapse are understood as cyclical transitions between resonant stability and non-resonant instability. Thus, the theory proposes a unifying paradigm that bridges the physical sciences with the social and human sciences.

Numerical simulations in one, two, and three dimensions demonstrated the existence of stable wave solutions and confirmed the conservation of energy, thereby validating the numerical and physical consistency of the theoretical model. A comparative analysis between the KDE-based simulations results and observational data from the Virgo Cluster exhibited strong agreement and statistical significance.

The consistency of the theory with existing physical frameworks—including Newtonian mechanics, relativity, electromagnetism, quantum mechanics, and superstring theory—was theoretically examined and shown to hold. These findings demonstrate that the source energy theory is not merely a speculative hypothesis but a robust theoretical structure that aligns with established physics while offering new perspectives.

Future research should focus on the empirical verification and exploration of practical application. As its range of applicability broadens, the proposed theory is expected to gain recognition not only within the physical sciences but also in interdisciplinary domains, establishing its universal value.

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