Spacetime-electromagnetic coupling model based on classifying electromagnetic field theory and interpretation of galactic rotation curve

abstract

In response to the dark matter puzzle reflected by the anomaly of galactic rotation curves, this paper proposes a **spacetime-electromagnetism coupling model** based on the previously constructed analog electromagnetic field theory, providing an alternative explanation from the perspective of "mass-spacetime dynamic correlation".

First, the core framework of the analog electromagnetic field theory is reviewed, including the definition of spacetime mass, the construction of the Lagrangian, the derivation of the Klein-Gordon equation, and its tensor representation. Subsequently, by modifying the Lagrangian density of Maxwell's theory, a spacetime-dependent permittivity $\varepsilon_{(r,t)}$ and permeability $\mu_{(r,t)}$ are introduced as carriers of the "electromagnetic properties" of spacetime, thereby establishing a coupling mechanism between electromagnetism and gravity. Specifically, the mass m of an object is jointly determined by $\varepsilon_{(r,t)}$ and the spacetime metric $g_{\mu v}$, moving beyond the "spacetime-matter" dualistic separation paradigm.

Under the assumption of a spherically symmetric spacetime, the Maxwell equations with time-varying $\varepsilon_{(r,t)}$ and $\mu_{(r,t)}$, as well as the spacetime curvature coupling equations, are derived using the principle of variation. This derivation clarifies the correlation between the analog electromagnetic field tensor and the Ricci tensor. Finally, for the galactic system, the formula for the tangential velocity of peripheral stars is derived. The results show that when $r >> r_s$ (where r_s is the characteristic scale radius), the velocity tends to a constant value, which is consistent with observational results.

Centered on the concept of "spacetime electromagnetic properties regulating mass and curvature", the model in this paper provides a new "electromagnetism-gravity unification" perspective for addressing the dark matter problem. Moreover, it maintains mathematical consistency with classical general relativity through the Lagrangian formalism, laying a foundation for subsequent observational verification.

Keywords: Analog electromagnetic field theory; Spacetime-electromagnetism coupling; Spacetime-dependent permittivity; Galactic rotation curve; Dark matter alternative model; Lagrangian variation

Introduction

The anomaly of the galactic rotation curve is one of the key unsolved problems in modern astrophysics. According to Newtonian gravitational theory and calculations based on the mass distribution of visible matter (such as stars and interstellar gas), the orbital velocity of stars in the outer regions of the Milky Way should decay with the increase of radial distance r following the relation $u \propto r^{-(1/2)}$. However, observational results show that when r exceeds a certain threshold, the velocity no longer decays but tends to a constant value—a phenomenon known as the "flat rotation curve" [1]. To resolve this contradiction, traditional theories introduce the "dark matter" hypothesis, which posits that an invisible dark matter halo surrounds galaxies; the gravitational contribution of this halo maintains the constant velocity of peripheral stars. Nevertheless, the particle properties of dark matter have not yet been confirmed by direct detection, and its distribution relies on model fitting, lacking fundamental theoretical support.

In previous studies, we constructed the analog electromagnetic field theory, which analogizes the description of spacetime to the form of electromagnetic fields. From this theory, we derived relativistic field equations (including the Klein-Gordon equation), preliminarily revealing the intrinsic connection between the quantum properties of spacetime and the motion of matter [2]. Building on this foundation, this paper further expands the physical connotation of the "analog electromagnetic field" and proposes a spacetime-electromagnetism coupling model: the permittivity $\varepsilon_{(r,t)}$ and permeability $\mu_{(r,t)}$ in vacuum are defined as spacetime-dependent functions, making them a bridge connecting electromagnetic interactions and spacetime curvature. Additionally, mass m is no longer a constant parameter but a dynamic quantity jointly determined by $\varepsilon_{(r,t)}$ and the spacetime metric $g_{\mu v}$. Through this mechanism, the flat rotation phenomenon of peripheral stars in the Milky Way can be explained by the radial distribution of spacetime's intrinsic properties—without the need to introduce dark matter.

1. Review of the core ideas of electromagnetic theory

The previous research "Construction of Electromagnetic Field Theory and Analogy with Relativistic Field Theory" focuses on the "direct simulation of gravity by electromagnetic field" and establishes the following core concepts and equations [2], which lays the foundation for this model.

一. Definition of time and space

1. The mass of any point in space-time is characterized by the distribution of matter per unit volume and the properties of space-time. The definition of mass per unit volume is:

$$\rho_{(r\cdot t)} = \left(\frac{\psi_{(r,t)}}{c}\right)^2$$

2. $\varepsilon = \frac{1}{C}\frac{\psi}{B}$, $\mu = -\frac{1}{c}\frac{B}{\psi}$

3. Considering the mass per unit volume, the Lagrangian is given by:

$\mathrm{L} = \mathrm{T} - \mathrm{V(r)} - \mathrm{E(r,t)} = \frac{1}{2}m_0 r'^2 - V(r,t) - \left(\psi_{(r,t)}{}^2\right)$ where $m_0 = (\frac{\psi_0}{c})^2$

4. equation： $\frac{\mathrm{d}}{\mathrm{dt}}\left(\frac{\partial L}{\partial r'}\right) - \frac{\partial L}{\mathrm{r}} = 0$

5. When $V(r,t) = B(r,t)^2$ is set, the following equation is obtained:

$$B\left[\nabla \times B - \frac{1}{c}\frac{\partial B}{\partial t}\right] + \psi\left[\nabla \times \psi - \frac{1}{c}\frac{\partial \psi}{\partial t}\right] = 0$$

6. Energy conservation:, $= \frac{1}{2}m_0\dot{r}^2 + \psi_{(r,t)}^2 + V(r,t) = Constant$, $m_0(\frac{\psi_0}{c})^2$

When equalizing: $B\nabla \times B - \psi\frac{1}{c}\frac{\partial \psi}{\partial t} = 0$

Order: That is: $\varepsilon = \frac{1}{C}\frac{\psi}{B}$, $\nabla \times B = \varepsilon\frac{\partial \psi}{\partial t}$

$\psi \times \psi - \mathrm{B}\frac{1}{c}\frac{\partial B}{\partial t} = 0$

Order: That is: $\mu = -\frac{1}{c}\frac{B}{\psi}$, $\nabla \times \psi = -\mu\frac{\partial B}{\partial t}$

7. And this leads to the Klein-Gordon equation.

$$k^2 = \nabla(\nabla\cdot) + \mathrm{c}\mu(\nabla \times \mu)\frac{\partial}{\partial t}$$

$$(\nabla^2 - \frac{1}{c^2}\frac{\partial^2\psi}{\partial^2 t} - k^2)\ \psi = 0$$

$$(\square - k^2)\psi = 0$$

8. Introduction to tensor notation:

$$F^{\mu\nu} = \begin{pmatrix} 0 & -\psi_x/c & -\psi_y/c & -\psi_z/c \\ \psi_x/c & 0 & -\mathrm{B}_z & \mathrm{B}_y \\ \psi_y/c & \mathrm{B}_z & 0 & -\mathrm{B}_x \\ \psi_z/c & -\mathrm{B}_y & \mathrm{B}_x & 0 \end{pmatrix}$$

$\nabla \times \psi = -\mu\frac{\partial B}{\partial t}$ corresponds to: $\nabla \times \psi = -\mu\frac{\partial B}{\partial t}$

$\nabla \times \psi = -\mu\frac{\partial B}{\partial t}$ corresponds to: $*F_{\mu\nu} = \frac{1}{2}\varepsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$

二. Construction of space-time electromagnetic coupling model:

1. So the $\psi_{(r,t)}$representation is just like an electromagnetic field, which is essentially a description of space – time. You can introduce:

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

2. The Lagrangian density is written as: In Maxwell's theory: $L = -\frac{1}{4\mu_0}F^{\mu\nu}F_{\mu\nu}$

Here, it is modified as: $L_{cov} = -\frac{1}{4\mu_{(r,t)}}F^{\mu\nu}F_{\mu\nu}\sqrt{-\boldsymbol{g}}$

($\sqrt{-\boldsymbol{g}}$ is the spacetime volume element, ensuring the covariance of the equations after variation.)

3. Variation: $\boldsymbol{\delta S = \delta\int L\sqrt{-g}d_x^4 = 0}$

4. $R_{\mu\nu} = F^{\alpha\beta}F_{\alpha\beta}\ g_{\mu\nu}$ which is a structure written by imitating the Einstein field equation. The complete relation is: $R_{\mu\nu} = \frac{1}{\mu_{(r,t)}}\left(\mathrm{F}_{\mu\alpha}\mathrm{F}_{\nu}^{\alpha} - \frac{1}{4}\mathrm{g}_{\mu\nu}\mathrm{F}_{\alpha\beta}\mathrm{F}^{\alpha\beta}\right)$
5. My idea is that $F^{\alpha\beta}F_{\alpha\beta}$ is variable, and the permittivity in vacuum should be a function of spacetime: $\mu = \mu_{(r,t)}$, thus causing the mass of an object $\rho_{(r\cdot t)}=(\frac{\psi_{(r,t)}}{c})^2$ to be different at different spacetime points, so as to explain the abnormal motion velocity of stars in the outer regions of the Milky Way.
6. Detailed explanation:

   Unification of electromagnetism and gravity: The permittivity ε is regarded as the "electromagnetic property" of spacetime and coupled with the spacetime metric $g_{\mu\nu}$ (similar to the coupling between the energy-momentum tensor of matter and spacetime in the Einstein field equation).

   Origin of mass: The mass m is determined by ψ, and ψ can be associated with the electromagnetic field $F_{\mu\nu}$ (for example, ψ is a certain combination of electromagnetic potentials). Therefore, m is indirectly jointly determined by $\mu_{(r,t)}$ and $F_{\mu\nu}$.

Derivation of variational fields:

The Maxwell $\mu_{(r,t)}$equations with time variations are given by:

$$\nabla_\mu\left(\frac{1}{\mu_{(r,t)}}F^{\mu\nu}\right) = 0$$

When $\mu = \mu_{(r)}$

$$\nabla_\mu\left(\frac{1}{\mu_{(r)}}F^{\mu\nu}\right) = 0$$

Consistency of equations:

1. From wave function to mass dynamics
2. From $m = (\frac{\psi}{c})^2$, the dynamics of mass (such as particle motion and gravitational effects) needs to be determined by the evolution equation of ψ. The wave equation with a mass term:

$$\left(\Box - \frac{m^2c^2}{\hbar^2}\right)\psi = 0$$

Maxwell's $\mu_{(r,t)}$equations with time variations:

$$\nabla_\mu\left(\frac{1}{\mu_{(r,t)}}F^{\mu\nu}\right) = 0$$

It describes the modification $\varepsilon_{(r,t)}$of the electromagnetic field by spacetime (through). It should be noted that:

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

A_μIt's called the electromagnetic potential.

7. Equation role: the unity of the Lagrange form

Classical general relativity (and all field theories) can derive the equations of the fields in a Lagrange L form: variate the Lagrange density

$\boldsymbol{\delta S = \delta \int L\sqrt{-g}d_x^4 = 0}$ where $\sqrt{-g}$ is the spacetime volume element),

Get the equation of motion for the field.

We can also obtain the classical general relativity equation through$\boldsymbol{\delta}\mathrm{S}_{\mathrm{EM}} = \boldsymbol{\delta \int L\sqrt{-g}d_x^4 = 0}$. Here, $\sqrt{-g}$ is the spacetime volume element $g = det(g_{\mu\nu})$, and since the metric \(g_{\mu\nu}\) has a Lorentz signature, g < 0).

The Labe density is written as: in Maxwell's theory: $L = -\frac{1}{4\mu_0}F^{\mu\nu}F_{\mu\nu}$

This is amended to read: $L_{cov} = -\frac{1}{4\mu_{(r,t)}} F^{\mu v} F_{\mu v}\sqrt{-\boldsymbol{g}}$

Comparison of Einstein-Hilbert action:

$$\delta s_{EH} = \frac{1}{2k}\boldsymbol{\delta}\int \sqrt{-g}Rd_x^4$$

Now we use $\psi$and B to represent the structure of space-time, which is called a "classical electromagnetic field", so we can use a "classical electromagnetic field" to directly simulate the "gravity" in the above equation:

$$\delta s_{EH} = \boldsymbol{\delta}\mathrm{S}_{\mathrm{EM}} = \frac{1}{2k}\boldsymbol{\delta}\int \sqrt{-g}Rd_x^4 = \boldsymbol{\delta}\int L_{cov}\sqrt{-\boldsymbol{g}}\boldsymbol{d_x^4}$$

So if you take this form, the above formula is actually the same:

$$R_{\mu v} = \frac{1}{\mu_{(r,t)}}\left(\mathrm{F}_{\mu\alpha}\mathrm{F}^{\alpha}_{\nu} - \frac{1}{4}\mathrm{g}_{\mu\nu}\mathrm{F}_{\alpha\beta}\mathrm{F}^{\alpha\beta}\right) \quad (1.5)$$

$F^{\alpha\beta}F_{\alpha\beta} = 2\ (B^2 - \frac{\psi^2}{c^2})$

Order: $2(B^2 - \frac{\psi^2}{c^2}) = \lambda_1$

The above equation is the result of simplifying this invariant $F^{\alpha\beta}F_{\alpha\beta}$. At this time,

$\lambda_1 = 2\left(\frac{B^2}{C^2} - c^2B^2\varepsilon^2\right) = 2(B^2 - \frac{\psi^2}{C^2}) = 2B^2(\frac{1}{C^2} - c^2\varepsilon^2)$

Order: $\lambda = -\frac{1}{4\mu_{(r,t)}}\ \lambda_1 = -\frac{1}{2\ \mu_{(r,t)}}\ (B^2 - \frac{\psi^2}{c^2})$

Under the assumption of isotropy of electromagnetic field, high symmetry of space-time and weak/average field, it can be approximated as:

$R_{\mu v} = \lambda g_{\mu v}$

This is called Einstein spacetime (Einstein spacetime)

- The Ricci tensor $R_{\mu v}$is the first contraction of the curvature tensor:

$$R_{\mu v} = R^{\lambda}_{\mu\lambda v}$$

- The Ricci scalar R is the second contracted form of the Ricci tensor:

$$R = g^{\mu v}R_{\mu v}$$

Variation of the action $g^{\mu v}$S with respect to

1. variation $\sqrt{-\boldsymbol{g}}$:

$$det(g) = g$$

$$\delta\, det(g) = det(g)g^{\mu v}\delta g_{\mu v}$$

$$\delta\sqrt{-g} = -\frac{1}{2}\sqrt{-g}g_{\mu v}\delta g^{\mu v}$$

$$R = g^{\mu v}R_{\mu v}$$

It is obtained that: $\delta R = \delta g^{\mu v}R_{\mu v} + g^{\mu v}\delta R_{\mu v}$

$$\delta R_{\mu v} = \nabla_{\lambda}\delta\Gamma^{\lambda}_{\mu v} - \nabla_{v}\delta\Gamma^{\lambda}_{\mu\lambda}$$

Integration of variations and use of partial integration

$$\delta\left(\sqrt{-g}R\right) = \sqrt[\delta]{-g}R + \sqrt{-g}\delta R$$

$$\delta S_{eh} = \frac{1}{2k}\int\left[-\frac{1}{2}\sqrt{-g}g_{\mu v}R\delta g^{\mu v} + \sqrt{-g}\left(\delta g^{\mu v}R_{\mu v} + g^{\mu v}\delta R_{\mu v}\right)\right]d_x^4$$

For the term containing $\delta R_{\mu\nu}$ (i.e., $g^{\mu\nu}\delta R_{\mu\nu}$), perform integration by parts, and utilize the property of the covariant derivative $\nabla_\lambda(\sqrt{-g}x^\lambda) = \sqrt{-g}\nabla^\lambda x_\lambda$ (where x^λ is an arbitrary vector). It can be proved that:

$$\int \sqrt{-g}g^{\mu\nu}(\nabla_\lambda \delta\Gamma^\lambda_{\mu\nu} - \nabla_\nu \Gamma^\lambda_{\mu\lambda})$$

Will be converted to a boundary term (zero at the infinite boundary $\delta g^{\mu\nu}$because the metric variation is usually zero at the boundary).

Extract the term proportional to $\delta g^{\mu\nu}\delta g^{\mu\nu}$. After neglecting the boundary terms, the remaining term proportional to $\delta g^{\mu\nu}$ is: $\frac{1}{2k}\int \sqrt{-g}\left(R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R\right)\delta g^{u\nu}d_x^4$

We obtain:

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \lambda g_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$$

$$G_{\mu\nu} = g_{\mu\nu}\left(\lambda - \frac{1}{2}R\right)$$

From the equation: $G_{\mu\nu} = \frac{8\pi G}{C^4}T_{\mu\nu}$, we know $\lambda \propto \frac{G}{C^4} = k_3\frac{G}{C^4}$ (k_3 is a proportionality coefficient.)

$$\lambda = -\frac{1}{2\mu_{(r,t)}}(B^2 - \frac{\psi^2}{C^2}) = k_3\frac{G}{C^4}$$

A. The traditional model is:

The specific mechanism of the "dark matter problem"

Since our model can unify quantum behavior with the structure of space-time, we can design a specific "mass-space-time" correlation mechanism for the galactic rotation curve:

The mass distribution of $\rho = \rho_{(r)}$ the Milky Way galaxy and its form: velocity u (r) = u (M), where M is the mass of the star.

The mass of the Milky Way galaxy (including stars, dark matter, etc.) is distributed in a ** spherical symmetry ($\rho_{(r)}$dark matter halo dominates the large scale)**. It is assumed that the mass density satisfies the NFW distribution (the typical distribution of dark matter halo):

$$\rho_{(r)} = \frac{\rho_0}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

Where $\rho_0 r_s r_s \approx$ 20kpcis the central density and is the characteristic scale radius (the Milky Way)

From $\rho \propto \psi^2$ (the field associated with the simulation mass), $\psi \propto \sqrt{\rho_{(r)}}$, we get (r), that is:

$$\psi_{(r)} = \psi_0\frac{\sqrt{r_s}}{\sqrt{r}\left(1+\frac{r}{r_s}\right)}$$

(As ψ_0 a constant, reflecting the central field strength)

B. Using our model:

$$vector\ field:\ B_{(r,\theta,\phi)} = B_r e_r + B_\theta e_\theta + B_\phi e_\phi$$

After supplementing the definition ε , μ of "stationary state, spherical symmetry" and, we can deduce the following in a consistent way:

It is calculated as $\psi(r)$follows:

$$\nabla_\mu\left(\frac{1}{\mu_{(r)}}F^{\mu\nu}\right) = 0$$

In the spherically symmetric spacetime (which is only related to the radial r), it is expanded as an example of the conservation of the radial component (with ν = r) to describe the conservation of the radial "classical electromagnetic flow"):

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\cdot\frac{1}{\mu_{(r)}}F^{0r}\right) + \text{angular}\ term = 0$$

Since the ball is symmetric, the angular term is zero, so the core equation is:

$$\frac{\partial}{\partial r}\left(r^2 \cdot \frac{1}{\mu_{(r)}} F^{0r}\right) = 0$$

The "analog electric field" ψ and the time-radial component F^{0r} of the electromagnetic field tensor satisfy

$$F^{0r} = \frac{\psi}{c}$$

$$\frac{\partial}{\partial r}\left(r^2 \cdot \frac{1}{\mu_{(r)}} \frac{\psi}{c}\right) = 0$$

Since the derivative is zero, the term in brackets is a constant (let's say K):

$$\psi(r) = \frac{kC\mu_{(r)}}{r^2}$$

$By\ \mu = -\frac{1}{c}\frac{B}{\psi}$,*we know that*

$$\mu_{(r)} = -\frac{1}{C}\frac{B_{(r)}}{\psi(r)}, \quad B_{(r)} = -C\psi(r)\mu_{(r)} = \frac{kC^2}{r^2}\mu_{(r)}{}^2$$

cause : $\lambda = -\frac{1}{2\mu_{(r)}}\left(B^2 - \frac{\psi^2}{C^2}\right) = k_3 \frac{G}{C^4}$

know : $-\frac{1}{2\mu_{(r)}}\left(\left(\frac{kC^2}{r^2}\mu_{(r)}{}^2\right)^2 - \frac{1}{C^2}\left(\frac{kC\mu_{(r)}}{r^2}\right)^2\right) = k_3 \frac{G}{C^4}$

$$-\frac{1}{2\mu_{(r)}}\left(\left(\frac{kC^2}{r^2}\mu_{(r)}{}^2\right)^2 - \frac{1}{C^2}\left(\frac{kC\mu_{(r)}}{r^2}\right)^2\right) = k_3 \frac{G}{C^4}$$

$$\mu_{(r)} \approx \frac{1}{C}$$

$$\psi(r) = \frac{k}{r^2}$$

$$\rho_{(r')} = \frac{1}{C^2}\left(\frac{k}{r'^2}\right)^2$$

Since r = 0 is meaningless, take $r_0 > 0$

M(mass) = $\int_{r_0}^{r} \rho_{(r')} 4\pi r'^2\, dr' = 4\pi k \frac{1}{C^2}\left(\frac{1}{r_0} - \frac{1}{r}\right)$

Spherical symmetry of the analog magnetic field B:

In the Milky Way, the "analog magnetic field" B is generated by the curl of the mass flow. Under spherical symmetry, B has a toroidal field (only the ϕ component), and the radial-polar angle components of the curl are:

$$(\nabla \times B)_r = \frac{1}{r}\frac{\partial}{\partial r}\left(rB_\phi(r)\right)$$

Substituting into the equation $\nabla \times B = \varepsilon\frac{\partial\psi}{\partial t}$, we get: $B_\phi(r) \propto \frac{1}{\mathrm{r}}$

Introduce proportionality coefficients: k_r and k_ϕ:

$$B_r = \frac{k_r}{r^2}e_r + \frac{k_\phi}{r}e_\phi$$

So this is what we call the contribution of quality, and the other contribution is

$$(\nabla \times B)_r = \frac{1}{r}\frac{\partial}{\partial r}\left(rB_\phi(r)\right)$$

Substitution $\nabla \times B = \varepsilon\frac{\partial\psi}{\partial t}$ equation: $B_\phi(r) \propto \frac{1}{\mathrm{r}} = \frac{A}{r}$ (where A is the proportionality coefficient)

$$\rho_B(\mathrm{r}) \propto B_\phi^2(r) \propto \frac{1}{\mathrm{r}^2}$$

$$M_{(B_\phi)} \propto \int_0^{\mathrm{r}} \frac{A^2}{r'^2} 4\pi r'^2\, dr' = 4A^2\pi\mathrm{r}$$

- **Let M(r) be the total mass within radius r of a galaxy**

$$M_{(r)} = M_{(mass)} + M_{(B_\phi)} = 4\pi k \frac{1}{C^2}\left(\frac{1}{r_0} - \frac{1}{r}\right) + 4A^2\pi\mathrm{r}$$

A is the proportion coefficient.

Application formula:

$\frac{GM_{(r)}m}{r^2} = \frac{mu^2}{r}$

The "flat rotation speed" of the stars in the outer Milky Way $r_0$is calculated as follows:

$$u = 2A\sqrt{\pi G}$$

It is consistent with the observations.

Summary

This idea provides an alternative perspective of "unification of electromagnetism and gravity" for the dark matter problem. The core lies in the changes of $m = (\frac{\psi}{c})^2$ and $V(r,t) = B(r,t)^2$, thereby altering the distribution of mass and spacetime curvature. In the future, we need to focus on the self-consistency of the mathematical model and observational verification to gradually improve the theoretical framework.

Conclusion

Based on the core framework of "directly simulating gravity with analog electromagnetic fields", this paper conducts research on the anomaly of the Milky Way rotation curve (the dark matter problem) by constructing a spacetime-electromagnetism coupling model. The main conclusions are as follows:

Core breakthrough of the theoretical framework

Revise the assumption in traditional Maxwell's theory that "the permittivity is a constant", and introduce a spacetime-dependent permittivity \(\varepsilon_{\left(r,t\right)}\), taking it as the quantitative carrier of the "electromagnetic property" of spacetime. Meanwhile, clarify the dynamic origin of mass m — $\rho_{(r\cdot t)} = \left(\frac{\psi_{(r,t)}}{c}\right)^2$, instead of the traditional "spacetime-matter" binary separation paradigm. Realize the closed-loop connection of "spacetime property → electromagnetic property → mass → gravitational effect". Moreover, there is no need to additionally introduce spacetime curvature terms, and gravity can be simulated only through the analog electromagnetic field tensor, maintaining the simplicity of the theoretical form.

Results of equation self-consistency verification

Based on the modified Lagrangian density $L_{cov} = -\frac{1}{4\mu_{(r,t)}}F^{\mu\nu}F_{\mu\nu}\sqrt{-\boldsymbol{g}}$, Maxwell's equations with time-varying $\mu_{(r,t)}$are derived through the variational principle. In the limit of flat spacetime $\mu_{(r,t)}$ being constant, they can degenerate into classical Maxwell's equations. After substituting m = $\left(\frac{\psi_{(r,t)}}{c}\right)^2$ into the Klein-Gordon equation, it can self-consistently describe the correlation between mass dynamics and the spacetime quantum state (wave function $\psi(r,t)$), and is also compatible with the weak field approximation of classical Newtonian gravity, proving that there is no contradiction in the model in terms of mathematical logic and physical compatibility.

Explanatory power for the Milky Way rotation curve

Under the assumption of "stationary and spherically symmetric spacetime" in the Milky Way, by analyzing the radial distribution of ($\psi(r)$) , ($\psi(r) = \frac{kC\mu_{(r)}}{r^2}$), the mass M(mass) = $\int_{r_0}^{r} \rho_{(r')}4\pi r'^2\,\mathrm{d}r' = 4\ \pi k\ \frac{1}{C^2}\left(\frac{1}{r_0} - \frac{1}{r}\right)$

The contribution of the analog magnetic field B to the mass is: $M_{(B_\phi)} = 4\ A^2\pi \mathrm{r}$

The total mass $M_{(r)} = M_{(mass)} + M_{(B_\phi)} = 4\ \pi k\ \frac{1}{C^2}\left(\frac{1}{r_0} - \frac{1}{r}\right) + 4\ A^2\pi\mathrm{r}$

Ultimately, the orbital velocity of stars $u = 2A\sqrt{\pi G}$ tends to a constant value, which is completely consistent with the observational results of the Milky Way rotation curve, providing an alternative explanation path for the dark matter problem from the perspective of "unification of electromagnetism and gravity".

Future research directions

Although this model initially explains the Milky Way rotation curve, it still needs to be deepened in two aspects. Firstly, establish a quantitative correspondence between "observation and theory" through observational data on the galactic scale. Secondly, expand the quantization description of the model, clarify the specific correlation forms of $\mu_{(r,t)}$, $\varepsilon_{(r,t)}$ with the analog electromagnetic potential A_v and the wave function ψ, and explore the quantization mechanism of simulating gravity with analog electromagnetic fields, so as to provide new ideas for solving the problem of "quantization of gravity".

In summary, the spacetime-electromagnetism coupling model proposed in this paper, with "directly simulating gravity with analog electromagnetic fields" as the core, avoids the "non-observability" dilemma of the dark matter hypothesis through the spacetimeization of permittivity and the dynamization of mass, while maintaining compatibility with classical field theory, providing a new theoretical perspective for understanding gravitational phenomena on the galactic scale.