Journal of Power and Energy Engineering, 2025, 13(11), 1-12
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

The Relationship between the Gravitational Field and the Speed of Light

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How to cite this paper: Jiang, J.Z. and Zhang, X.Q. (2025) The Relationship between the Gravitational Field and the Speed of Light. *Journal of Power and Energy Engineering*, **13**, 1-12.
https://doi.org/10.4236/jpee.2025.1311001

Received: June 18, 2025
Accepted: November 4, 2025
Published: November 7, 2025

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Abstract

Based on the analogical analysis of the gravitational field and the electrostatic field, along with the hypothesis of the superluminally spiral motion of space during the inflationary phase of the Big Bang, we have formulated the relationship formulas that strictly defines the connections among the gravitational field, mass/density, and the speed of light. The findings indicate that mass represents the gravitational flux across the global surface, the density of an object is the divergence of this gravitational flux, and the fundamental nature of the gravitational field is the vector sum of half the square of the speed of light gradient and the acceleration field of spatial motion at any given instant. These results not only elucidate the fundamental nature of mass, density, and the gravitational field but also lay a theoretical foundation for the unification of the four fundamental forces in the universe.

Keywords

Gravitational Acceleration, Mass and Density, Superluminal Motion, Planck Time, The Universal Big Bang

1. Introduction

According to Newton's law of universal gravitation, any object with mass generates a gravitational field around it, and other masses are attracted by this field, while the speed of light is a fundamental constant in nature, representing the maximum speed at which light can travel in a vacuum. From the perspective of classical physics, the gravitational field and the speed of light belong to different physical categories, thus they seem to have no direct connection. However, in the development of modern physics, scientists have gradually realized that there might be a deeper relationship between them. For instance, in general relativity, Einstein proposed that gravity is not a traditional "force", but rather a geometric effect caused by the curvature of spacetime due to mass and energy. Under this theoretical framework, the path of light is also affected by the gravitational field, exhibiting a phenomenon similar to refraction. This phenomenon has been verified in multiple astronomical observations, such as the measurement of starlight deflection during a total solar eclipse. Additionally, some theoretical studies have attempted to explore the potential connection between gravity and the speed of light through the Planck time, a fundamental unit based on the combination of Planck's constant, the speed of light, and the gravitational constant, which is considered the time scale at which quantum gravitational effects might become apparent. Although some have tried to derive the relationship between the gravitational field and the speed of light from the Planck time expression, this approach often falls into the problem of circular reasoning because its premise already assumes a certain connection between these physical quantities, thus leading to a lack of independence and logical rigor in the conclusion.

To overcome these issues and further explore the essential relationship between the gravitational field and the speed of light, this paper adopts a new research method—by making an analogy between the gravitational field and the electrostatic field. The electrostatic field is generated by electric charges and exerts a force on other charges; similarly, the gravitational field is produced by mass and exerts a gravitational force on other masses. These two fields are highly similar in mathematical form, both following the inverse-square law and can be described by potential functions for their spatial distribution. By leveraging this analogy, we can introduce some mature theories and methods from electrostatics into the study of the gravitational field, thereby providing new ideas for establishing a quantitative relationship between the gravitational field and the speed of light. Based on this, we attempt to construct a theoretical model that connects the intensity of the gravitational field with the speed of light from a strict mathematical perspective. This model not only considers the basic principles of classical gravitational theory but also incorporates concepts from relativity and quantum mechanics, aiming to reveal the possible intrinsic connection between gravity and the speed of light. If this relationship can be successfully established and experimentally verified, it will provide an important theoretical basis for unifying the four fundamental forces of nature (*i.e.*, gravity, electromagnetic force, weak nuclear force, and strong nuclear force), and may also offer a new perspective for understanding the basic structure and evolution of the universe.

2. An Analogical Analysis of the Gravitational Field and the Electrostatic Field

According to **Table 1**, the gravitational field and the electrostatic field exhibit the following similarities. Similarity in the form of force expressions: Both expressions indicate that the force is inversely proportional to the square of the distance. Specifically, the gravitational force is proportional to the product of the mass, while the electrostatic force is proportional to the product of the charge. Moreover, both of them are long-range forces. Similarity in the applicable conditions of the forces: The law of universal gravitation is applicable to the gravitational interaction between two point masses, and Coulomb's law for the electrostatic force is applicable to the interaction between two point charges.

With reference to **Table 1**, based on the definitions of relevant physical quantities in the electrostatic field of a stationary electric charge $\boldsymbol{Q}$ in a stationary spherical vacuum space $\boldsymbol{R}$ as depicted in **Figure 1**, we define the gravitational field $\boldsymbol{a}$, gravitational potential φ_g, vacuum gravitational constant ϵ_0, gravitational displacement vector $\boldsymbol{F}$, and the total gravitational flux ϕ_g over the entire spherical surface generated by a spherical object with mass M where the radius, density, surface area, and volume are r_0, ρ_g, S and V respectively located at the center O of the space $\boldsymbol{R}$ as follows

$$\boldsymbol{a} = -\frac{GM}{r^2}\boldsymbol{e}_r, \tag{1}$$

$$\varphi_g = -GM/r, \tag{2}$$

$$\epsilon_0 = 1/4\pi G, \tag{3}$$

$$\boldsymbol{F} = \epsilon_0 \boldsymbol{a} = -\frac{M}{4\pi r^2}\boldsymbol{e}_r, \tag{4}$$

$$\phi_g = \oiint_S -\boldsymbol{F}\cdot \mathrm{d}\boldsymbol{S} = \frac{M}{4\pi}\oiint_S \frac{1}{r^2}\mathrm{d}S = M. \tag{5}$$

Here, G is the universal gravitational constant, and r is the radial distance from the center O of the spherical space $\boldsymbol{R}$. At this instant, the motion velocity of the space $\boldsymbol{R}$ is zero. The relationship between the gravitational field $\boldsymbol{a}$ and the gravitational potential φ_g can be expressed as

$$\boldsymbol{a} = -\nabla\varphi_g = \nabla(GM/r). \tag{6}$$

According to the divergence theorem, taking the spherical surface S of object M as the Gaussian surface, Equation (5) can also be expressed as

$$\oiint_S -\boldsymbol{F}\cdot \mathrm{d}\boldsymbol{S} = -\int_V \nabla\cdot\boldsymbol{F}\mathrm{d}V = \int_V \rho_g \mathrm{d}V. \tag{7}$$

Based on Equation (7), we can obtain

$$\nabla\cdot\boldsymbol{F} = \frac{1}{4\pi G}\nabla\cdot\boldsymbol{a} = -\rho_g. \tag{8}$$

From the above-mentioned theoretical analysis, it can be concluded that Equation (5) implies that mass is equivalent to the gravitational flux over the entire spherical surface generated by it. Equation (8) implies that the density of an object is the divergence of the gravitational flux generated by the mass of that object.

Table 1. An analogical analysis of gravitational field and electrostatic field in a vacuum.

	The gravitational field	**The electrostatic field**
The formula for the force field	$\boldsymbol{a} = -\frac{GM}{r^2}\boldsymbol{e}_r$	$\boldsymbol{E} = -\frac{kQ}{r^2}\boldsymbol{e}_r$

Continued

Gravitational potential φ_g /electromagnetic scalar potential φ	$\varphi_g = -GM/r$	$\varphi = -kQ/r$
Vacuum gravitational constant ϵ_0 /vacuum permittivity ε_0	$\epsilon_0 = 1/4\pi G$	$\varepsilon_0 = 1/4\pi k$
Gravitational displacement vector $\boldsymbol{F}$ /electric displacement vector $\boldsymbol{D}$	$\boldsymbol{F} = \frac{1}{4\pi G}\boldsymbol{a} = \epsilon_0 \boldsymbol{E} = -\frac{M}{4\pi r^2}\boldsymbol{e}_r$	$\boldsymbol{D} = \frac{1}{4\pi k}\boldsymbol{E} = \varepsilon_0 \boldsymbol{E} = -\frac{Q}{4\pi r^2}\boldsymbol{e}_r$
Total gravitational flux ϕ_g /total electric flux ϕ	$\phi_g = \oiint_S -\boldsymbol{F}\cdot \mathrm{d}\boldsymbol{S} = \frac{M}{4\pi}\oiint_S \frac{1}{r^2}\mathrm{d}S = M$	$\phi = \oiint_S -\boldsymbol{D}\cdot \mathrm{d}\boldsymbol{S} = \frac{Q}{4\pi}\oiint_S \frac{1}{r^2}\mathrm{d}S = Q$
The curls of gravitational displacement vector/electric displacement vector	$\nabla\cdot\boldsymbol{F} = \epsilon_0 \nabla\cdot\boldsymbol{a} = -\rho_g$	$\nabla\cdot\boldsymbol{D} = \varepsilon_0 \nabla\cdot\boldsymbol{E} = \rho$
The force field represented by potentials	$\boldsymbol{a} = -\nabla\varphi_g - \partial\boldsymbol{V}_s/\partial t$	$\boldsymbol{E} = -\nabla\varphi - \partial\boldsymbol{A}/\partial t$
Notes	$\boldsymbol{V}_s$ is the motion speed of vacuum space, $\boldsymbol{A}$ is the magnetic vector potential, k is the electrostatic force constant.	

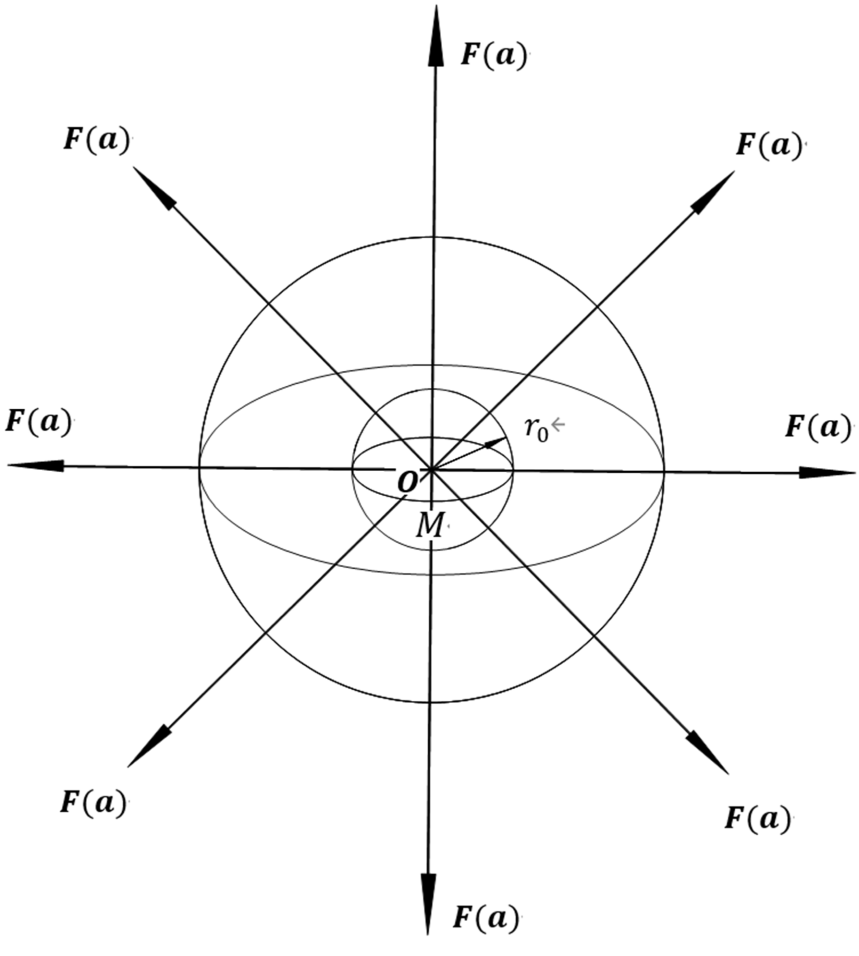

Figure 1. Gravitational field and displacement vector produced by a mass M.

3. The Gravitational Fields of a Black Hole and a Moving Space

In the framework of the general theory of relativity, when the radius r of an object with a mass M satisfies a radius R_s, the object collapses into a black hole.

Here, R_s is the Schwarzschild radius [1], which is expressed as

$$R_s = 2GM/C^2. \tag{9}$$

Substituting Equation (9) into Equation (6), it can be deduced that when $r \le R_s$, the gravitational field of the black hole can be written as

$$\boldsymbol{a} = \nabla\left(GM/R_s\right) = \nabla\left(C^2/2\right). \tag{10}$$

At this instant, the black hole is in a stable equilibrium state, and the space in which it resides is stationary.

$$\boldsymbol{E} = -\nabla\varphi - \partial\boldsymbol{A}/\partial t. \tag{11}$$

In accordance with the relationship Equation (11) between the electric field and the magnetic vector potential $\boldsymbol{A}$/electromagnetic scalar φ and the hypothesis that Equation (10) also holds true when r is greater than R_s, the gravitational field of a moving space can be expressed as

$$\boldsymbol{a} = -\nabla\varphi_g - \partial\boldsymbol{V}_s/\partial t = \nabla\left(C^2/2\right) - \partial\boldsymbol{V}_s/\partial t. \tag{12}$$

In Equation (12), the first term on the right-hand side represents the static gravitational field component generated by the stationary mass M located at the center of space. Its value is equal to the gradient of $C^2/2$. The second term represents the dynamic gravitational field component arising from the motion speed $\boldsymbol{V}_s$ of space.

4. The Hypothesis of the Superluminally Spiral Motion in the Inflationary Period after the Big Bang

It is hypothesized that in the earliest phase (inflationary period) after the Big Bang (within 1 - 10^{13} t_P), that is, within the cosmic epoch from 10^{-44} s to 10^{-31} s [2], space moved in a right-handed spiral at the superluminal speed of C [3] (see **Figure 2**), expanding to a spherical space $\boldsymbol{R}(R,\theta,\varphi)$ with a radius of R_0. The period of the moving spiral line of space $\boldsymbol{R}$ is Planck time t_P, its step length λ and frequency are Planck length ι_P and C/ι_P. Meanwhile, its polar angular coordinate φ is constantly equal to φ_0 and tends to zero [4]. Thus, in the spherical coordinate system $\boldsymbol{R}$, the radial velocity V_R, tangential velocity V_θ, and polar velocity V_φ of this spiral motion of space can be described as follows[5]

$$V_R = \partial R/\partial t = C, \tag{13}$$

$$V_\theta = R_0 \sin\varphi_0\, \partial\theta/\partial t = R_0 \sin\varphi_0\, C/\lambda = C, \tag{14}$$

$$V_\theta = R_z\omega = R_z/t_P = R_z C/\lambda = C, \tag{15}$$

$$V_\varphi = R_0 \cos\varphi_0\, \partial\varphi_0/\partial t = R_0\, \partial\varphi_0/\partial t = 0. \tag{16}$$

From Equation (14) and Equation (15), we can obtain that

$$\varphi_0 = \sin\varphi_0 = \lambda/R_0. \tag{17}$$

$$R_z = \lambda = \iota_P, \tag{18}$$

Here, R_z is. the spiral radius when $r = R_0$.

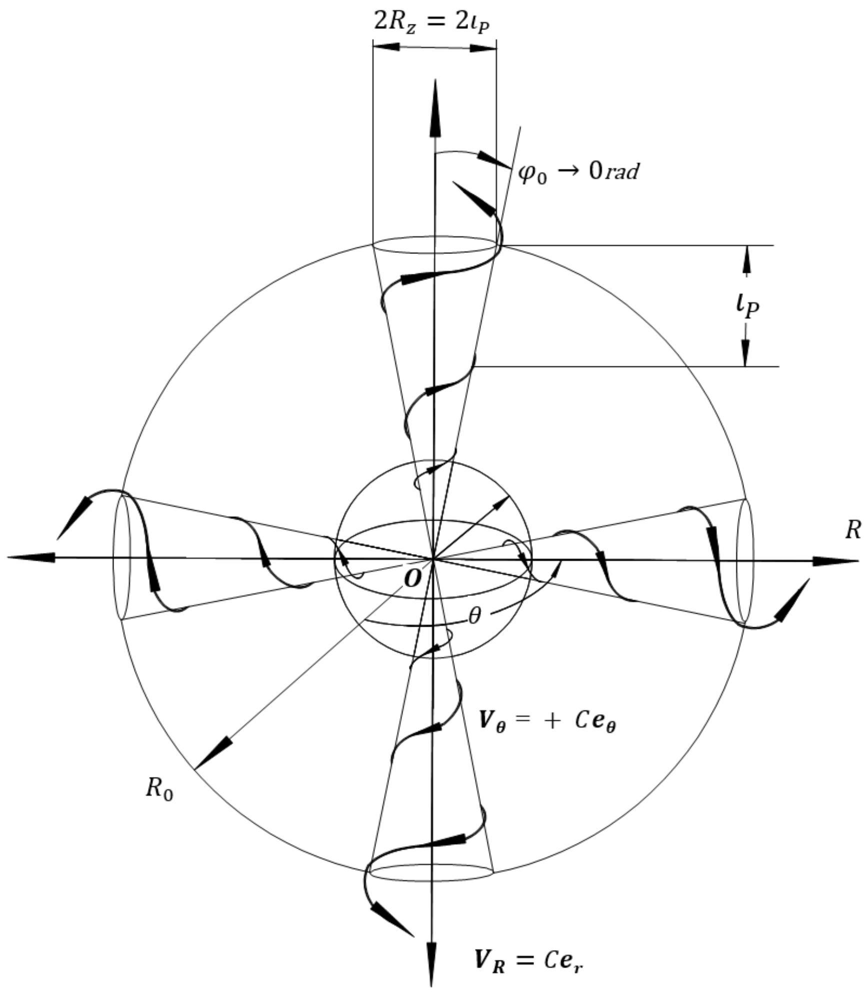

Figure 2. The superluminally spiral motion of space R during the inflationary period of the universal Big Bang.

5. The Relationship between the Gravitational Field and the Speed of Light

5.1. The Gravitational Field at the Singularity before the Big Bang

At this instant, the Big Bang has not taken place yet, space $\boldsymbol{R}$ has not come into being and there is no motion of space when the singularity is analogous to a black hole. As is analyzed in Section 3, the gravitational field at this moment can be expressed as

$$\boldsymbol{a} = \nabla\left(C^2/2\right) = \infty. \tag{19}$$

5.2. The Gravitational Field during the Inflationary Period of the Big Bang

According to the mass-energy conversion equation of special relativity, during the inflationary process of the Big Bang, the potential energy of the singularity was continuously transformed into the kinetic energy of the motion of space $\boldsymbol{R}$, while this kinetic energy was constantly converted into the matter in the early stage of the universe. Consequently, this kind of spatial motion speed was constantly decreasing [5].

From the definition of the Planck time [6], we have

$$G\hbar = t_P^2 C^5 . \tag{20}$$

where $\hbar$ is the reduced Planck constant. Suppose that $G\hbar$ is a constant under all circumstances. The only variable parameters are the contemporaneous speed of light C and the period t_P of the spiral motion of space $\boldsymbol{R}$.

During the inflationary period of the Big Bang, the period of the spiral motion of space is the Planck time t_P $5.39121\times10^{-44}\ \text{s}$. At this instant, space has just emerged from the singularity explosion, and the gravitational field of space can be approximated as that of a black hole. In the early stage of the Big Bang after inflation, when the strong nuclear force has just separated from the "primeval unified force" [5], the period of the spiral motion of space $\boldsymbol{R}$ is $0.8854\times10^{-31}\ \text{s}$. At this moment, the superluminal speed C decreased to the current speed of light C_0 and kept invariable. Combining with Equation (20), we can obtain that the superluminal speed C and the expansion distance R_0 of space during the inflationary period of the Big Bang can be expressed as

$$C = \sqrt[5]{\left(\frac{0.8854\times10^{-31}}{5.39121\times10^{-44}}\right)^2} C_0 = 7.69\times10^4 C_0 , \tag{21}$$

$$R_0 = C10^{13} t_P = 7.69\times10^{17} C_0 t_P \sim 10^{-17}\ \text{m} , \tag{22}$$

where $C_0 = 2.98\times10^8\ \text{m/s}^2$. Equation (21) indicates that in extremely strong gravitational fields, such as those near black holes, the variation of the speed of light becomes particularly evident. This conclusion has been corroborated by relevant theories and observational results [7]. According to Equation (12), the gravitational field of space at this moment can be expressed as

$$\begin{aligned} \boldsymbol{a} &= \nabla\left(C^2/2\right) - \partial \boldsymbol{C}/\partial t = -\frac{C^2}{2R_0}\boldsymbol{e}_r + \frac{C}{10^{13} t_P}\boldsymbol{e}_r = -\left(\frac{C^2}{2\times10^{13} C t_P} - \frac{C}{10^{13} t_P}\right)\boldsymbol{e}_r \\ &= \frac{C}{2\times10^{13} t_P}\boldsymbol{e}_r = \frac{7.69\times10^4 C_0}{2\times10^{13} t_P}\boldsymbol{e}_r \sim 10^{43}\boldsymbol{e}_r\ \text{m/s}^2 . \end{aligned} \tag{23}$$

Equation (23) reveals that during the inflationary epoch of the Big Bang, the magnitude of the gravitational field in space was 10^4 times that of the strong nuclear force field, with its direction radially outward. In this stage, the immense potential energy of the gravitational field caused the space to expand rapidly to 10^{43}-10^{60} times its initial scale [8]. Ultimately, this led to the formation of the space-time structure of our present-day universe.

5.3. The Gravitational Field When the Strong Nuclear Force Completed its Separation from the "Primeval Unified Force"

Supposing that approximately one second after the Big Bang, it dropped from the superluminal speed C to C_0; while it corresponding expansion acceleration declined to $10^{39}\ \text{m/s}^2$ and the strong nuclear force completed its separation from the

" primeval unified force" [5], gradually transforming energy into elementary particles, successively generating quark-antiquark pairs, gluon-antigluon pairs, and electron-positron pairs, ultimately forming a plasma known as "quark soup" [9].

At this juncture, the spiral light-speed motion of space $\boldsymbol{R}$ needed to drive the motion of massive particles in space. The tangentially spiral velocity V_θ was equivalent to the tangential spiral motion velocity of particles in space and could not exceed the speed of light [5]. Assuming that the mechanism of particles revolving around the core of radially spatial motion at this moment was consistent with that of electrons in the ground state revolving around the hydrogen nucleus [10], we could obtain:

$$V_\theta = C_0/137. \tag{24}$$

As known from ref. [5], the spiral light-speed motion frequency of space $\boldsymbol{R}$ at this moment was the spiral motion period τ_2 of the vacuum scalar wave, that is, $\tau_2 = \omega_P^{-1} = \sigma_0/\omega^2\varepsilon_0 = 0.8854\times10^{-31}\ \text{s}$. Here, ω_P is the oscillation frequency of the vacuum scalar wave, $\omega \sim 10^{14}\ \text{Hz}$ is the frequency of the source light wave generating the vacuum scalar wave, $\sigma_0 \sim 10^{-14}\ \text{S/m}$ and $\varepsilon_0 = 8.854\times10^{-12}\ \text{F/m}$ are the vacuum conductivity and vacuum permittivity respectively.

Consequently, the spiral motion frequency of space at this moment was

$$\omega = 1/\tau_2 = 1.129\times10^{31}\ \text{Hz}, \tag{25}$$

and its step length was shown as

$$\lambda = C_0\tau_2 = 2.654\times10^{-23}\ \text{m}. \tag{26}$$

Simultaneously, the expansion radius R_1 of space $\boldsymbol{R}$ had to reach the range of the strong nuclear force, *i.e.*, 2×10^{-15} m [11]. From **Figure 3**, we can be given that

$$V_R = \partial R/\partial t = C_0, \tag{27}$$

$$V_\theta = R_1 \sin\varphi_0\, \partial\theta/\partial t = R_1\sin\varphi_0\, C_0/\lambda = C_0/137, \tag{28}$$

$$V_\theta = R_z\omega = R_z/t_P = R_z C_0/\lambda = C_0/137, \tag{29}$$

$$R_1 = 2\times10^{-15}\ \text{m}, \tag{30}$$

$$R_z = \lambda/137 = 1.937\times10^{-25}\ \text{m}, \tag{31}$$

$$\varphi_0 \approx \sin\varphi_0 = R_z/(137R_1) \sim 10^{-11}\ \text{rad}. \tag{32}$$

$$\cos\varphi_0 \approx 1. \tag{33}$$

According to Equation (12), the gravitational field of space at this moment can be expressed as

$$\begin{aligned}
\boldsymbol{a} &= \nabla\left(C_0^2/2\right) - \partial\boldsymbol{V}_s/\partial t = -\partial\boldsymbol{V}_R/\partial t - \partial\boldsymbol{V}_\theta/\partial t \\
&= -\boldsymbol{e}_r\,\partial V_R/\partial t - \boldsymbol{e}_\theta\,\partial V_\theta/\partial t - V_R\,\partial\boldsymbol{e}_r/\partial t - V_\theta\,\partial\boldsymbol{e}_\theta/\partial t \\
&= -\boldsymbol{e}_r\,C_0/\tau_2 - \boldsymbol{e}_\theta\,C_0/137\tau_2 - \boldsymbol{e}_\theta\,C_0\sin\varphi_0/\tau_2 \\
&\quad + \boldsymbol{e}_r\,C_0\sin\varphi_0/137\tau_2 + \boldsymbol{e}_\varphi\,C_0\cos\varphi_0/137\tau_2 \\
&\approx -10^{39}\boldsymbol{e}_r - 10^{37}\left(\boldsymbol{e}_\theta - \boldsymbol{e}_\varphi\right) + 10^{26}\boldsymbol{e}_r\ \text{m/s}^2.
\end{aligned} \tag{34}$$

Equation (34) reveals the relationship between the gravitational field and the speed of light C_0 when the strong nuclear force completed its separation from the "primeval unified force". In Equation (34), the first term C_0/τ_2 corresponds to the strong nuclear force field generated by the radial linear motion $C_0\boldsymbol{e}_r$; the second term $C_0/137\tau_2$ undoubtedly represents the electromagnetic fields produced by its tangential rotational motion $V_\theta\boldsymbol{e}_\theta$ of $\boldsymbol{R}$. Owing to the presence of two mutually perpendicular forces within the electromagnetic forces, namely the electric field force and the magnetic field force, the electromagnetic forces in Equation (34) exhibits two directions: $\boldsymbol{e}_\theta$ and $\boldsymbol{e}_\varphi$; the third term $C_0\sin\varphi_0/137\tau_2$ might be the weak nuclear force field associated with the cone angle φ_0 of the spatial micro-conical spiral motion of $\boldsymbol{R}$.

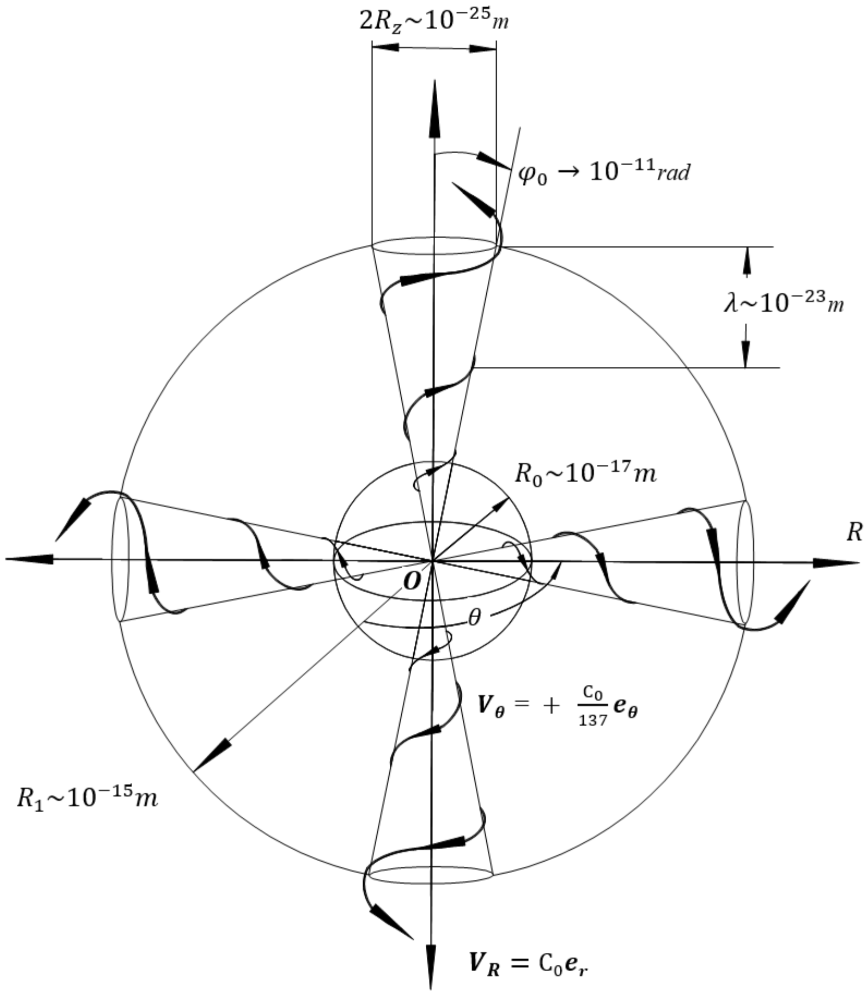

Figure 3. The spiral light speed motion of space R when the strong nuclear force completed its separation from the "primeval unified force".

5.4. The Gravitational Field When the Electromagnetic Forces Completed Their Separation from the "Primeval Unified Force"

About one minute after the Big Bang, the radial motion speed of space in $\boldsymbol{R}$ decreased to $C_0/137$, and the electromagnetic forces (10^{37}m/s^2) completed its separation from the " primeval unified force". Owing to the absorption of a considerable amount of energy, quarks and gluons continued to coalesce into protons and antiprotons under the action of the spirally centripetal force fields generated by the space motions [5]. Subsequently, protons and electrons combined to form neutrons, while antiquarks, anti-gluons, antiprotons and positrons were repelled to the fringes of space $\boldsymbol{R}$ due to the repulsion property between opposite torsion fields and did not participate in the constitution of our universe [12]. The conclusion that the vacuum was filled with neutrons and protons for a certain period after the Big Bang, as believed by scientists, is derived from nuclear tests, nuclear fusion experiments, and long-term observations of stars and cosmic rays [13].

5.5. The Gravitational Field When the Weak Nuclear Force Completed Its Separation from the "Primeval Unified Force"

Approximately 380,000 years after the Big Bang, the radial moving speed of space $\boldsymbol{R}$ decreased to 10^{-13} times the speed of light, namely 10^{-5} m/s. The weak nuclear force (with a magnitude of 10^{26} m/s^2) completed its separation from the "original single force". At this time, a proton captured an electron to form the first hydrogen atom, and electrically neutral gas clouds gradually started to form in the universe. Photons were freed from their confinement and began to be released, causing the universe to start emitting light and brightening up. As space $\boldsymbol{R}$ continued to expand, the temperature of the universe dropped rapidly. When it dropped to 1 billion degrees Celsius, neutrons could no longer exist freely. Under the action of the weak nuclear force, hydrogen nuclear fusion was initiated, and neutrons began to combine with hydrogen atoms to form deuterium, helium, or other light elements. Chemical elements started to form during this period, and approximately 30% of the helium abundance in the universe [14] was formed at this time.

5.6. The Gravitational Field When Gravity Completed Its Separation from the "Primeval Unified Force"

Around one billion years after the Big Bang, the radial moving speed of space $\boldsymbol{R}$ decreased to 10^{-30} m/s [5]. At this moment, gravity completed its separation from the "primeval unified force", and the gravitational field of space $\boldsymbol{R}$ can be expressed as

$$\begin{aligned}\boldsymbol{a} &= -\partial \boldsymbol{V}_S / \partial t \\ &= -\boldsymbol{e}_r\, \partial V_R / \partial t - \boldsymbol{e}_\theta\, \partial V_\theta / \partial t - V_R\, \partial \boldsymbol{e}_r / \partial t - V_\theta\, \partial \boldsymbol{e}_\theta / \partial t \\ &\approx -V_S / \tau_2\, \boldsymbol{e}_r - V_S / 137\tau_2\, \boldsymbol{e}_\theta + V_S / 137\tau_2\, \boldsymbol{e}_\varphi \\ &\approx -10^{-30} / \tau_2\, \boldsymbol{e}_r = -g\boldsymbol{e}_r.\end{aligned} \tag{35}$$

That is to say, the acceleration field of the radial expanding motion of the current space $\boldsymbol{R}$ is precisely the gravitational field of the Earth at present. As time went on, under the influence of the gravitational force $-g\boldsymbol{e}_r$, the first galaxy emerged in space $\boldsymbol{R}$. Subsequently, numerous other galaxies, stars, planets, and various celestial bodies came into being, leading to the vast and boundless universe that we humans observe today [15].

6. Conclusion

Based on the analogical analysis of the gravitational field and the electric field, we formulate the relational equations among the gravitational field, mass, density, and the speed of light. The findings not only elucidate the nature of mass and the gravitational field but also discover the relationship between the gravitational field and the speed of light, which present an interesting hint on intrinsic relationship of the four fundamental forces in the universe.

Acknowledgements

I would like to thank my wife, Ms. Xue Jingwen, and my sister, Jiang Minye for their hard family work and support for my creation of this thesis.

Author Contributions

Conceptualization: JJZ (JIANG Jian-zhong);
Methodology: ZXQ (ZHANG Xiang-qian);
Investigation: ZXQ;
Visualization: JJZ;
Funding acquisition: ZXQ;
Project administration: JJZ;
Supervision: ZXQ;
Writing - original draft: JJZ;
Writing - review & editing: JJZ.

Data and Materials Availability

All data are available in the main text or the supplementary materials.

Conflicts of Interest

Authors declare that they have no competing interests.

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