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How Could Linearized General Relativity and Quantum Gravitation Explain Dark Matter at CMB

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Abstract

In previous articles, we proposed explaining the dark matter (DM) component, without invoking exotic matter, by utilizing the second component of General Relativity (GR) responsible for the Lense-Thirring effect. While the first component is the " g " Newtonian field, we designate this second component as the " k " gravitic field. In GR, the k-field originates from mass currents; however, our previous studies indicate that such mass currents cannot account for the magnitude of the k-field required to explain the entirety of DM. Given the similarity between the k-field and the magnetic field in electromagnetism (EM), we propose explaining its unexpectedly high value through a quantum approach to gravity, drawing an analogy with magnetic fields in EM which can only be explained by spin, a concept from quantum mechanics. We apply these concepts to explain the DM of the CMB. This makes it possible to obtain the order of magnitude of these fundamental concepts. Although this work is exploratory, these values could be used to test theories of Quantum Gravity and the concepts could also allow us to define a linear approximation of Quantum gravity inspired by the linearization of GR. This explanation could also constitute a step towards justifying the existence of a uniform gravitic field k_0 (proposed in previous articles) capable of explaining the DM of current astrophysical structures.

Subject Areas

Quantum Gravity, Astrophysics

Keywords

Dark Matter, Gravitation, Quantum Mechanics, Quantum Gravitation, CMB

1. Introduction

Faced with countless observations over many years [1] [2], the theory reveals the necessary presence of a component [3] [4] called dark matter (DM). These observations occur at all scales of the Universe, starting from that of galaxies [5] [6], but not at smaller scales (galactic cores, stellar systems, star clusters, etc.). This component is called dark because its origin is completely unknown and is entirely invisible directly. While at scales smaller than that of galaxies, all measured physical effects are based on known physical entities that are very well modeled by the theory, the DM component is known only through these exclusively gravitational effects, which is entirely unprecedented. Indeed, to date, every material physical entity is naturally subject to both gravitational interactions as defined by General Relativity (GR) and electromagnetic interactions (EM). And this is very well verified up to the scale of galaxies, planets, stars, stellar systems, star clusters and even the interior of galaxies, their velocity problem only appearing at their edges. Thus, we are led to propose two avenues of explanation, either the presence of so-called exotic matter because it is different from anything we know to date (for the reasons mentioned above), which is the most commonly accepted explanation, or a theoretical gap, for example a Modification of Newtonian dynamics, MOND [7] or a lack of knowledge of the impact of the non-linear terms of GR [8] [9].

For several years, a new theoretical solution has been proposed in this second approach, using the second component of GR (the one responsible for the Lense-Thirring effect) to explain this DM component without exotic matter [10]. The principle is quite simple to grasp when one relies on the linearization of GR (GRL), thanks to which this second gravitational field (which we will call "gravitic") takes exactly the same form as the magnetic field with respect to the electric field of EM (itself similar to the Newtonian term). This solution necessarily implies the unexpected existence of a uniform gravitic field k_0 in which the Universe is immersed, in a way quite similar to the magnetic fields of magnets but in a gravitational context [11]. The GRL leads to the same equations as those of EM, which are therefore called the Einstein-Maxwell equations [12] [13]. This solution gives a value for this uniform gravitational field on the order of $10^{-16.7} \le k_0 \le 10^{-16.2}$ [14]. This same value allows us to obtain, among other things:

- The rotation speeds at the edges of galaxies [14].
- The masses of clusters [10].
- The Tully-Fisher relation with the break for superspirals, *i.e.*, $M > 10^{11.5}$ solar masses and $v > 340\ \mathrm{km \cdot s^{-1}}$ [15].
- The MOND theory and its parameter $a_0 \approx 10^{-10}\ \mathrm{m \cdot s^{-2}}$ [16].
- The gravitational lenses without exotic matter [17].

Furthermore, the vectorial aspect of this uniform field implies, among other things [11]:

- Coplanar alignment of dwarf galaxies.
- Warping of galaxies.
- Appearance of walls and filaments (and therefore large voids).

The advantage of this solution is that it does not involve a new unknown mass and does not modify GR, but rather uses a method that GR makes possible by integrating a uniform gravitic field that does not originate from mass currents, in the same way that Maxwell's equations allow the integration of uniform magnetic fields that do not necessarily originate from charge currents, as with magnets and their field arising from the quantum notion of spin. Thus, in this solution, the existence of this permanent and relatively uniform graviic field could be explained in the same way as the fields that can be produced by magnets. This is the subject of the study addressed in this article. This work explores this approach by drawing on a complete analogy with EM. We therefore justify this approach because the Einstein-Maxwell equations are equivalent to Maxwell equations and lead to the existence of the same kind of terms, *i.e.* the same mathematical expressions, the newtonian field in GR equivalent to electric field in EM and gravitic field in GR equivalent to magnetic field in EM. This analogy leads us to propose a linearized form of a quantum mechanics of gravitation. Indeed, since this analogy stems from GRL, one might expect this quantum mechanics of gravitation to be linearized as well.

2. Analogy of GRL and EM

The linearization of the field equations of the GR leads to the Einstein-Maxwell equations [13] [18] similar to the Maxwell equations of EM:

$$\begin{aligned} &\boldsymbol{g} = -\nabla\phi; \quad \boldsymbol{k} = \nabla\wedge\boldsymbol{H} \\ &\nabla\wedge\boldsymbol{g} = 0; \quad \nabla\wedge\boldsymbol{k} = -4\pi\frac{G}{c^2}\rho\boldsymbol{v} \\ &\nabla\cdot\boldsymbol{g} = -4\pi G\rho; \quad \nabla\cdot\boldsymbol{k} = 0 \end{aligned} \tag{1}$$

where $\boldsymbol{k}$ is the 2nd component of GRL (component that we will call "gravitic field") at the origin of the Lense-Thirring effect observed in the Gravity Probe B mission [19] [20] and $\boldsymbol{H}$ is the vector potential of the gravitic field. ρ is the mass density.

The linearization of the geodesic equations of the GR, combined with the Einstein-Maxwell Equations (1) leads to the following movement equations [13] [18] [21] for a particle of mass m_p:

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = m_p\left[\boldsymbol{g} + 4\boldsymbol{v}\wedge\boldsymbol{k}\right] \tag{2}$$

According to the Einstein-Maxwell Equations (1) and the movement Equations (2), $\boldsymbol{k}$ is equivalent to the magnetic field in EM.

In EM, the field and motion equations can be derived from the Lagrangian ([22]):

$$L = -m_p c^2\sqrt{1-\frac{v^2}{c^2}} + q\boldsymbol{A}\cdot\boldsymbol{v} - qV \tag{3}$$

The first term corresponds to the Lagrangian of the free particle, and the last two to the EM field in which the particle is located (with $\boldsymbol{A}$ the potential vector of EM, V the electrical potential and q the charge of the particle).

The GRL metric 7 allows us to write the GRL potential 8. By analogy, the Lagrangian for GRL can be written:

$$L = -m_p c^2 \sqrt{1 - \frac{v^2}{c^2}} + 4m_p \boldsymbol{H} \cdot \boldsymbol{v} - m_p \phi_{GRL} \tag{4}$$

In QM, the EM Lagrangian yields the following Hamiltonian ([23]):

$$H = \frac{1}{2m_p} (\boldsymbol{p} - q\boldsymbol{A})^2 + qV \tag{5}$$

By analogy, the Hamiltonian for GRL can be written ([24]):

$$H = \frac{1}{2m_p} (\boldsymbol{p} - 4m_p \boldsymbol{H})^2 + m_p \phi_{GRL} \tag{6}$$

Our idea is therefore to follow the same approach as in QM for the study of a particle with spin in a weak magnetic field $\boldsymbol{B}$, an approach that leads to the Pauli Hamiltonian (see, for example Eq. XII.34 of [23]) which corresponds to add a new term to the Hamiltonian 5, the magnetic dipole interaction $\boldsymbol{\mu}_S \cdot \boldsymbol{B}$. The new term is defined by a magnetic moment $\boldsymbol{\mu}_S = \gamma_S \hbar \boldsymbol{S}$ with $\boldsymbol{S}$ the spin of the particle.

In the solution we are exploring, the existence of a gravitic spin $\boldsymbol{S}_{GR}$ is a first physical hypothesis we propose by analogy with the spin $\boldsymbol{S}$ found in QM. The expressions used later, 10 for the potential vector and 11 for the gravitic moment, adopt the mathematical and physical definitions from EM and QM. However, since this definition of the magnetic moment relies on the existence of Planck's constant, we make a second physical hypothesis regarding the existence of a gravitational Planck constant, which appears in Equation (11) in the same way as it does in EM and QM.

3. Preamble on the Solution of DM by the GRL and Its Uniform Gravitic Field $\boldsymbol{k}_0$

While for a magnet its field is carried by the assembly of atomic spins (with coherent orientation), in our astrophysical framework, as proposed in [14], this gravitic field k_0 is very likely carried by galaxy clusters. However, this explanation presents two problems. First, neighboring clusters must each carry a relatively parallel gravitic field to maintain the uniform gravitic field k_0 over long distances. This coherence between neighboring clusters can certainly only be explained by the prior presence of a gravitic field that would tend to induce this coherence, as in paramagnetic or diamagnetic materials in EM. Second, the DM component is detected [25] in the cosmic microwave background (CMB), but at this stage of the Universe, clusters are still far from existing, and the Universe is quite homogeneous; no astrophysical structure is yet present. We are then quite naturally led to propose a solution that addresses these two problems.

To continue the theoretical parallel with EM, we can expect this gravitic field to fundamentally originate from a gravitic spin similar to the spins of quantum mechanics (QM). This elementary gravitic spin field would provide a DM component for the CMB (as we will see) and would supply the external gravitic field to which the clusters would be subjected, causing their gravitic fields to be relatively parallel for neighboring clusters (required to obtain a relatively uniform $\boldsymbol{k}_0$). We would therefore have the following evolutionary scheme: elementary particles at the time of the CMB would carry a gravitic spin, and the gravitational interaction would tend to bring together particles with a coherent orientation, favoring the birth of structures with a similar and increasing gravitic orientation. This would generate large-scale particle clouds (the future clusters) carrying a significant gravitic field. Then, these clusters, through their assembly, would generate this relatively uniform residual field k_0 over very long distances.

To test this idea, we will revisit the modeling of QM spins, adapting it and then applying it to GRL. The result will be to provide theoretical concepts with their orders of magnitude, which could be used to test quantum mechanics of gravitation, or even to provide a linear approximation towards which a quantum mechanics of gravitation might tend.

4. From GRL to QM of Gravitation

We will now show that the principle of magnetic spins applied to gravitic spins allows us to recover the component of the DM measured in the CMB. The gravitic moments of gravitic spins will be defined in the same way as the magnetic moments of magnetic spins. They too will be proportional to Planck's constant. Our approach will therefore create a bridge between QM and GRL, potentially illuminating a path towards a QM of gravitation.

As indicated in [14], the GRL allows us to obtain the following metric with the Newtonian gravitational potential $\phi_{New} = -\frac{GM}{r}$ and $\boldsymbol{H}$ the vector potential of gravitation (from the GRL):

$$\mathrm{d}s^2 = \left(1 + \frac{2\phi_{New}}{c^2}\right)c^2\mathrm{d}t^2 - \frac{8\boldsymbol{H}\cdot\mathrm{d}\boldsymbol{x}}{c}c\mathrm{d}t + \cdots \tag{7}$$

We can therefore deduce that, as a first approximation, we can write the weak-field gravitational potential generated by a particle of mass m:

$$\phi_{GRL} = \phi_{New} - 4\boldsymbol{H}\cdot\boldsymbol{v} = -\frac{Gm}{r} - 4\boldsymbol{H}\cdot\boldsymbol{v} \tag{8}$$

As can be seen in the GRL equations, we can go from the EM expressions to the GRL expression (with a factor of 4 for the force expression) essentially by making the following two substitutions [26]:

$$\epsilon_0 \Leftrightarrow \frac{1}{4\pi G}; \quad \mu_0 \Leftrightarrow \frac{4\pi G}{c^2} \tag{9}$$

As in QM and according to the analogy explained in Section 2 for Pauli Hamiltonian, we take into account the gravitic dipole interaction. Based on the vector potential of EM for a magnetic dipole, we can write the vector potential of the

GRL:

$$\boldsymbol{H} = \frac{G}{c^2}\frac{\boldsymbol{\mu}_{GR} \wedge \boldsymbol{r}}{r^3} \tag{10}$$

With the gravitic moment $\boldsymbol{\mu}_{GR}$ of the gravitic spin $\boldsymbol{S}_{GR}$ which is written in the image of the EM with a factor which is denoted g_{GR} which is the equivalent of the Landé factor and $\hbar_{GR}$ the equivalent of the Planck constant for a gravitational context:

$$\boldsymbol{\mu}_{GR} = g_{GR}\hbar_{GR}\boldsymbol{S}_{GR} \tag{11}$$

The potential field can then be written as:

$$\phi_{GRL} = -\frac{Gm}{r} - 4\frac{G}{c^2}\left(\frac{\boldsymbol{\mu}_{GR} \wedge \boldsymbol{r}}{r^3}\right)\cdot\boldsymbol{v} \tag{12}$$

We want to determine the amount of DM at the time of the CMB. At this stage of the Universe's evolution, no structure has formed, and there is a circulation of high-energy particles. Hydrogen and helium make up the vast majority of its composition. This results in a dense, highly agitated cloud of protons and neutrons. In what follows, we will use the term "protons" to refer to both protons and neutrons, given the similarity in size and mass between protons and neutrons. A proton will experience the following potential from its neighbor at a mean distance d_p (the subscript "*p*" indicates the proton's characteristics):

$$\begin{aligned}\phi_{p-p\_GRL} &= -\frac{G}{d_p}\left(m_p + \frac{4}{c^2}\frac{\left(\boldsymbol{\mu}_{p\_GR} \wedge \boldsymbol{d}_p\right)\cdot\boldsymbol{v}_p}{d_p^2}\right)\\ &= -\frac{Gm_p}{d_p}\left(1 + \frac{4}{c^2}g_{p\_GR}\hbar_{GR}\frac{\left(\boldsymbol{S}_{p\_GR} \wedge \boldsymbol{d}_p\right)\cdot\boldsymbol{v}_p}{d_p^2 m_p}\right)\end{aligned} \tag{13}$$

In this expression, within the parentheses of the first equation, the left-hand side (m_p) represents the baryonic mass of the proton, and the right-hand side the mass equivalent of the DM (which in our solution is not an exotic mass but a gravitic field) due to the proton. Therefore, within the parentheses of the second equation, the right-hand side represents the proportion of DM per proton relative to the baryonic mass. This proportion remains valid when summing over all protons, thus representing the overall baryonic masses of the Universe (left-hand side) and the proportion of the DM term (right-hand side).

According to CMB observations [25], the total measured mass would be 5% baryonic mass and 25% DM. In other words, in the preceding expression, the part in parentheses, "1" corresponds to the baryonic mass (5%) and the second term to the DM mass, which must be 5 times greater (25%). At the time of the CMB, we should therefore have, as a first approximation (we justify this approximation in 5):

$$\frac{4}{c^2}g_{p\_GR}\hbar_{GR}\frac{\left(\boldsymbol{S}_{p\_GR} \wedge \boldsymbol{d}_p\right)\cdot\boldsymbol{v}_p}{d_p^2 m_p} \approx 5 \tag{14}$$

With a proton of mass $m_p \approx 1.67\times10^{-27}$ kg a distance between two protons at

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the CMB time of $d_p \approx 1.5\times10^{-3}$ m and a thermic agitation generating velocities on the order of $9\times10^3\ \mathrm{m\cdot s^{-1}} \approx 3\times10^{-5}c$, we have:

$$\begin{aligned}&\left\|\frac{4}{c^2}g_{p\_GR}\hbar_{GR}\frac{\left(\boldsymbol{S}_{p\_GR}\wedge\boldsymbol{d}_p\right)\cdot\boldsymbol{c}}{d_p^2 m_p}\right\|\\&\approx\frac{4\times3\times10^{-5}}{3\times10^8\times1.5\times10^{-3}\times1.67\times10^{-27}}g_{p\_GR}\hbar_{GR}S_{p\_GR}\\&\approx1.5\times10^{17}g_{p\_GR}\hbar_{GR}S_{p\_GR}\end{aligned}\tag{15}$$

In EM, the Landé factor is a few units (for the proton, for example, $g_p \approx 5.586$) and the spin value $\left\|\boldsymbol{S}_p\right\|$ is an integer or half-integer (for the proton, for example, $S_p = \frac{1}{2}$). Therefore, we expect g_{p_GR} to be on the order of a few units and S_{p_GR} to be an integer or half-integer. In EM, for the proton, we would thus have $g_pS_p \approx 2.793$. We would therefore expect similar orders of magnitude and to simplify we assume $g_{p\_GR}S_{p\_GR} \approx 1$. According to CMB measurements, we would then have (with 14 and 15) an order of magnitude of the gravitational Planck constant:

$$\begin{aligned}&g_{p\_GR}S_{p\_GR}\hbar_{GR}\approx\frac{5}{1.5\times10^{17}}\\&\Rightarrow\hbar_{GR}\approx3\times10^{-17}\ \mathrm{m^2\cdot kg\cdot s^{-1}}\approx3\times10^{17}\hbar\end{aligned}\tag{16}$$

In our approach, the quantum of energy of the gravitational wave would be:

$$E = h_{GR}\nu \approx 2\times10^{-16}\nu \tag{17}$$

5. Discussion

One might wonder whether the non-linear terms of GR could modify this result, in particular relation 19. However, if we calculate the value of this gravitational field, it is indeed quite weak, justifying the use of GRL to obtain a good order of magnitude:

$$\left\|\phi_{p-p\_GRL}\right\| \approx \frac{Gm_p}{d_p} \approx \frac{6\times10^{-11}\times1.67\times10^{-27}}{1.5\times10^{-3}} \approx 10^{-34}\ \mathrm{m^2\cdot s^{-2}} \tag{18}$$

And for the gravitic dipole interaction, it then leads:

$$\left\|4\frac{G}{c^2}\left(\frac{\boldsymbol{\mu}_{GR}\wedge\boldsymbol{r}}{r^3}\right)\cdot\boldsymbol{v}\right\| \approx 5\times\left\|\phi_{p-p\_GRL}\right\| \tag{19}$$

This term is still weak.

We hypothesize that, locally, the interaction of a particle with a neighboring dipole will be perceived as a correction to the baryonic mass of this particle within the framework of an exotic mass model (that does not explicitly account for that dipole). We assume therefore that each particle undergoes this correction from a neighboring dipole. This implies an assumption that more distant neighbors contribute a negligible correction and that, according to Kepler's theorem, only about ten neighbors would need to be considered. However, since we are working in terms of orders of magnitude, we do not deem it necessary to account for these ten neighbors, especially given that the value of $g_{p\_GR}S_{p\_GR}$ is itself unknown and assumed to be on the order of unity. We therefore assume that the correction applied locally to each particle is equivalent to the correction applied to the ensemble of particles. This is why we apply the proportion of DM measured in the CMB to each individual particle. It should also be noted that this hypothesis avoids anisotropy at the global scale of the CMB, since the non-perpendicular orientation of the dipoles (required to ensure a non-zero dipole interaction term) is necessary only at the level of immediately neighboring particles. This ensures consistency with the high degree of homogeneity observed in the CMB.

The value of the gravitational Planck constant depends linearly on $g_{p\_GR}S_{p\_GR}$. If $g_{p\_GR}S_{p\_GR} \approx 10$, the constant will be 10 times smaller ($\hbar_{GR} \approx 3\times10^{-18}\ \mathrm{m}^2\cdot\mathrm{kg}\cdot\mathrm{s}^{-1}$). If $g_{p\_GR}S_{p\_GR} \approx 10^{-1}$, the constant will be 10 times larger ($\hbar_{GR} \approx 3\times10^{-16}\ \mathrm{m}^2\cdot\mathrm{kg}\cdot\mathrm{s}^{-1}$).

Our study proposes an explanation to DM for the CMB that attributes a predominant role to Quantum Gravity. This attempt is based on the following postulates, definitions, and relationships:

- The spin of the gravitation that we call the gravitic spin S_{p_GR}.
- The gravitic moment of the gravitic spin (following the same definition 11 as QM).
- The potential vector of the gravitation (following the same relation 10 as QM).
- The quantification of the gravitation (following the same relation 17 as QM).
- The predominant role of Quantum Gravity for the CMB's DM.

In this theoretical context, CMB observations would provide information on the entities of Quantum Gravity.

6. Conclusion

In this study, we have explored an original and hypothetical approach to explain the DM component in the CMB. By using notions and expressions similar to those of QM to define equivalent notions of gravitic spin and gravitic spin moment, this conceptual "projection" would allow the CMB's DM quantities to provide fundamental characteristics for Quantum Gravity, in particular an equivalent to a Planck constant in this gravitational context. This could pave the way for a QM of gravitation through a linearized approach of GR or allow existing Quantum Gravity theories to be tested in their linearized version. This explanation of the CMB's DM by the gravitic spin of elementary particles would also allow for a more comprehensive justification of the DM solution by a uniform gravitic field k_0 proposed in [10] [11] [14]. Indeed, these gravitic spins could lead, in a top-down scenario, to the formation of structures from the largest scales to the smallest (walls, filaments then clusters, galaxies, etc.) with coherent gravitic fields in these neighboring structures (as in EM with paramagnetic and diamagnetic materials that become magnetized under the influence of an external field). These fields would then extend and be maintained (even if residual) throughout the Universe, from one scale to a subscale. And to conclude, we can add that this approach using elementary gravitic moments could also allow the obtaining of repulsive gravity, which could explain dark energy [26].

Data Availability

All data generated or analysed during this study are included in this published article.

Conflicts of Interest

The author declares no conflicts of interest.

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