physical sciences forum

MDPI

Proceeding Paper

On the Field Strength of Vacuum Energy and the Emergence of Mass †

Mohammed B. Al-Fadhli

College of Science, University of Lincoln, Lincoln LN6 7TS, UK; malfadhli@lincoln.ac.uk or mo.fadhli7@gmail.com

† Presented at the 2nd Electronic Conference on Universe, 16 February–2 March 2023; Available online: https://ecu2023.sciforum.net/.

Abstract: Large inconsistencies in the outcome of precise measurements of Newtonian gravitational 'constant' were identified throughout more than three hundred experiments conducted up to date. This paper illustrates the dependency of the Newtonian gravitational parameter on the curvature of the background and the associated field strength of vacuum energy. Additionally, the derived interaction field equations show that the boundary interaction of conventional and vacuum energy densities and their spin-spin correlations contribute to the emergent mass. Experimental conditions are recommended to achieve consistent outcomes of the parameter precision measurements, which can directly falsify or provide confirmations to the presented field equations.

Keywords: Field strength of vacuum energy; Newtonian gravitational parameter

Citation: Al-Fadhli, M.B. On the Field Strength of Vacuum Energy and the Emergence of Mass. *Phys. Sci. Forum* **2023**, *3*, x. https://doi.org/10.3390/xxxxx

Published: 3 March 2023

1. Introduction

The Newtonian gravitational 'constant' G plays a crucial role in theoretical physics, astronomy, geophysics, and engineering. About three hundred experiments attempted to ascertain the value of G up to date. However, the significant inconsistencies in their results have made it unfeasible to reach a consensus on an exact value. Many of them are precision measurements with a relative uncertainty of only 12 to 19 parts per million [1–5].

The achievement of such a low level of uncertainty can indicate that the margin of systematic errors in experiments is narrower than generally anticipated. At the same time, the significant inconsistencies among measurements' outcomes imply that there could be phenomena that are not yet accounted for in the current framework of physics. This study investigates the impact of the background curvature on the value of G, and the influence of boundary interactions and spin-spin correlations on the emergence of mass.

2. Newtonian Gravitational Parameter

The Sun flows in a spatially flat spacetime background, based on General Relativity, where its induced curvature is proportional to its energy density and flux. On the other hand, the Earth flows in a curved background (curved bulk) due to the Sun's presence, where its induced curvature is affected by the bulk curvature, $\mathcal{R}$, in addition to its energy density and flux. To incorporate the bulk influence, a modulus of spacetime deformation, E_D, is utilized. The modulus can be expressed in terms of the bulk resistance to localized curvature or in terms of the field strength of the bulk by using the Lagrangian formulation of energy density existing in the bulk as a manifestation of vacuum energy density as

$$E_D = \frac{T_{\mu\nu} - \frac{1}{2}T g_{\mu\nu}}{R_{\mu\nu}/\mathcal{R}} = \frac{-\mathcal{F}_{\lambda\rho}\mathcal{F}^{\lambda\rho}}{4\mu_0} \tag{1}$$

where $\mathcal{F}_{\lambda\rho}$ is the field strength tensor of the bulk and μ_0 is vacuum permeability.

By incorporating the bulk influence, the Einstein–Hilbert action can be extended to

$$S = E_D \int_C \left[\frac{R}{\mathcal{R}} + \frac{L}{\mathcal{L}}\right] \sqrt{-g}\; d^4\rho \tag{2}$$

where R is the Ricci scalar representing a localized curvature, which is induced in the bulk by a celestial object that is regarded as a 4D relativistic cloud-world of metric g_{uv} and Lagrangian density L, respectively, whereas $\mathcal{R}$ is the scalar curvature of the 4D conformal bulk of metric $\tilde{g}_{\mu\nu}$ and Lagrangian density $\mathcal{L}$ as its internal stresses and momenta reflecting its curvature. Since E_D is constant with regard to the extended action under the constant vacuum energy density condition; and by considering the evolution of the bulk owing to the expansion of the Universe, a dual-action concerning the energy conservation on global (bulk) and local (cloud-world) scales can be introduced as follows

$$S = \int_B \left[\frac{-\mathcal{F}_{\lambda\rho}\tilde{g}^{\lambda\gamma}\mathcal{F}_{\gamma\alpha}\tilde{g}^{\rho\alpha}}{4\mu_0}\right]\sqrt{-\tilde{g}}\; \int_C \left[\frac{R_{\mu\nu}g^{\mu\nu}}{\mathcal{R}_{\mu\nu}\tilde{g}^{\mu\nu}} + \frac{L_{\mu\nu}g^{\mu\nu}}{\mathcal{L}_{\mu\nu}\tilde{g}^{\mu\nu}}\right]\sqrt{-g}\; d^4\rho\; d^4\sigma \tag{3}$$

Applying the principle of stationary action in [6] yields

$$\frac{R_{\mu\nu}}{\mathcal{R}} - \frac{1}{2}\frac{R}{\mathcal{R}}g_{\mu\nu} - \frac{R\mathcal{R}_{\mu\nu}}{\mathcal{R}^2} + \frac{R(\mathcal{K}_{\mu\nu} - \frac{1}{2}\mathcal{K}\hat{q}_{\mu\nu}) - \mathcal{R}(K_{\mu\nu} - \frac{1}{2}K\hat{q}_{\mu\nu})}{\mathcal{R}^2} = \frac{\hat{T}_{\mu\nu}}{\mathcal{T}_{\mu\nu}} \tag{4}$$

These interaction field equations can be interpreted as indicating that the cloud-world's induced curvature, R, over the bulk's conformal (background) curvature, $\mathcal{R}$, equals the ratio of the cloud-world's imposed energy density and its flux, $\hat{T}_{\mu\nu}$, to the bulk's vacuum energy density and its flux, $\mathcal{T}_{\mu\nu}$, throughout the expanding/contracting Universe. The field equations can describe the interaction and flow of a 4D relativistic cloud-world of intrinsic $R_{\mu\nu}$ and extrinsic $K_{\mu\nu}$ curvatures through a 4D conformal bulk of intrinsic $\mathcal{R}_{\mu\nu}$ and extrinsic $\mathcal{K}_{\mu\nu}$ curvatures. The boundary term given by the extrinsic curvatures of the cloud-world and bulk is only significant at high energies when the difference between the induced and background curvatures is significant. By transforming intrinsic and extrinsic curvatures of the bulk [6], comparing Einstein field equations with Equation (1) and then substituting to Equation (4), the interaction field equations can be simplified to

$$R_{\mu\nu} - \frac{1}{2}R\hat{g}_{\mu\nu} - (K_{\mu\nu} - \frac{1}{2}K\hat{q}_{\mu\nu}) = \frac{8\pi G_{\mathcal{R}}}{c^4}\hat{T}_{\mu\nu} \tag{5}$$

where $\hat{g}_{\mu\nu} = g_{\mu\nu} + 2\mathcal{R}_{\mu\nu}/\mathcal{R} - 2\bar{\bar{g}}_{\mu\nu}$, or can be expressed as $\hat{g}_{\mu\nu} = g_{\mu\nu} + 2\tilde{g}_{\mu\nu} - 2\bar{\bar{g}}_{\mu\nu}$ because $\mathcal{R}_{\mu\nu}/\mathcal{R} = \mathcal{R}_{\mu\nu}/\mathcal{R}_{\mu\nu}\tilde{g}^{\mu\nu} = \tilde{g}_{\mu\nu}$, is the conformally transformed metric, which takes into account contributions from the cloud-world metric, $g_{\mu\nu}$, as well as the intrinsic and extrinsic curvatures of the bulk based on its metrics, $\tilde{g}_{\mu\nu}$ and $\bar{\bar{g}}_{\mu\nu}$ (intrinsic-equivalent metric) respectively, whereas Einstein spaces are a subclass of the conformal space [7]. $\hat{T}_{\mu\nu} = T_{\mu\nu} - t_{\mu\nu} = \left(2L_{\mu\nu} - L\hat{g}_{\mu\nu}\right) - \left(2l_{\mu\nu} - l\hat{q}_{\mu\nu}\right)$ is a conformal stress-energy tensor that is defined by including the Lagrangian of the energy density and flux of the cloud-world, $T_{\mu\nu}$, and the electromagnetic energy flux from its boundary, $t_{\mu\nu}$, over the conformal time. These interaction field equations could remove the singularities and satisfy a conformal invariance theory. From Equations (5) and (1), the Newtonian gravitational parameter is

$$G_{\mathcal{R}} = \frac{c^4}{8\pi E_D}\mathcal{R} \tag{6}$$

where $\mathcal{R} = \mathcal{R}_{\mu\nu}\tilde{g}^{\mu\nu}$ is the scalar curvature of the bulk. According to Equation (6), $G_{\mathcal{R}}$ is proportional to $\mathcal{R}$ and reflects the field strength of vacuum energy because any changes in the bulk's metric, $\tilde{g}_{\mu\nu} := \mathcal{R}$, changes the field strength of the bulk, $\mathcal{F}_{\lambda\rho}$, because of the constant modulus, $E_D = -\mathcal{F}_{\lambda\rho}\tilde{g}^{\lambda\gamma}\mathcal{F}_{\gamma\alpha}\tilde{g}^{\rho\alpha}/4\mu_0$. In addition, although the ground state of $\mathcal{R}$ at the local present Universe appears to be spatially flat, it could have a small temporal curvature reflecting the present value of G. The dependency of $G_{\mathcal{R}}$ on the curvature of the bulk is discussed and visualized as follows.

Regarding the Earth, Figure 1 shows the curvature of its background, the curved bulk owing to the Sun's presence. In this curved background, both Earth and Moon are further inducing different curvature configurations depending on their positions. For instance, at Point A, the Earth's background curvature is influenced by the Moon's position as shown by the blue and red-dotted curves. As the background curvature has different values at this point, $G_{\mathcal{R}}$ is predicted to have different values according to Equation (6). In addition, other nearby planets can influence the background curvature configuration.

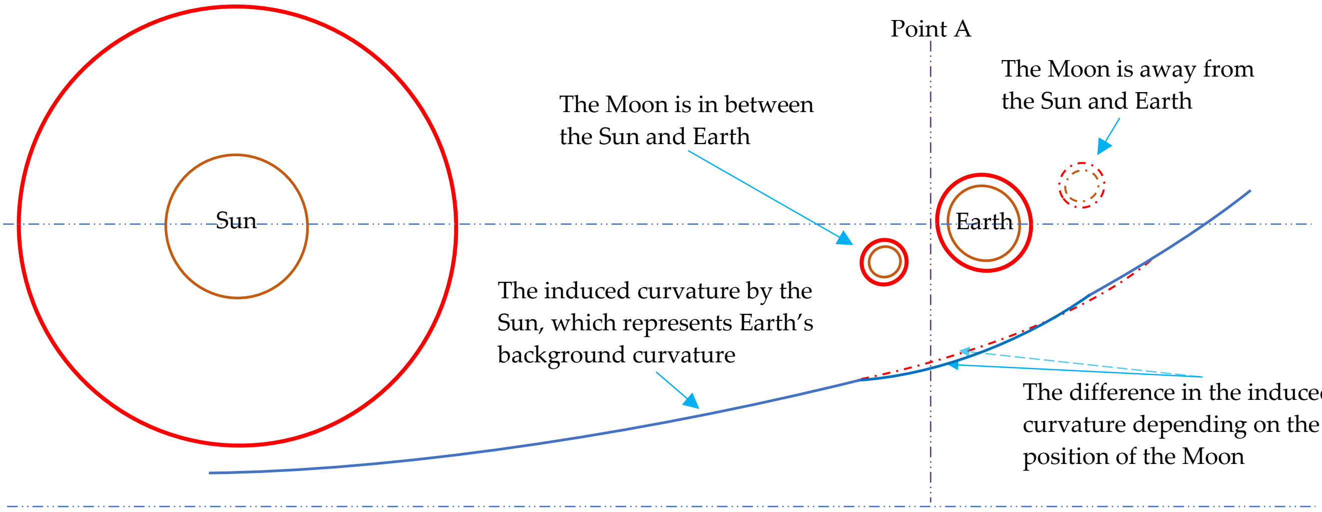

Figure 1. The blue curve represents the induced curvature by the Sun, which signifies the curvature of the background with respect to the Earth and Moon. Concerning both planets, they in turn are inducing further curvature in their background as visualized beneath them by the blue curve. On the other hand, when the Moon is at the away position (dotted circles), an altered induced curvature configuration is shown by the red dotted curve.

Figure 2 shows six of $G_{\mathcal{R}}$ values by measurements: BIPM-14 [8], BIPM-01 [9], UCI-14 [10], UZur-06 [11], JILA-10 [12] and HUST-05 [13]. These values were among those adopted in the CODATA (Committee on Data for Science and Technology) 2014 of the recommended value of (6.67408 ± 0.00031) x$10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ [14].

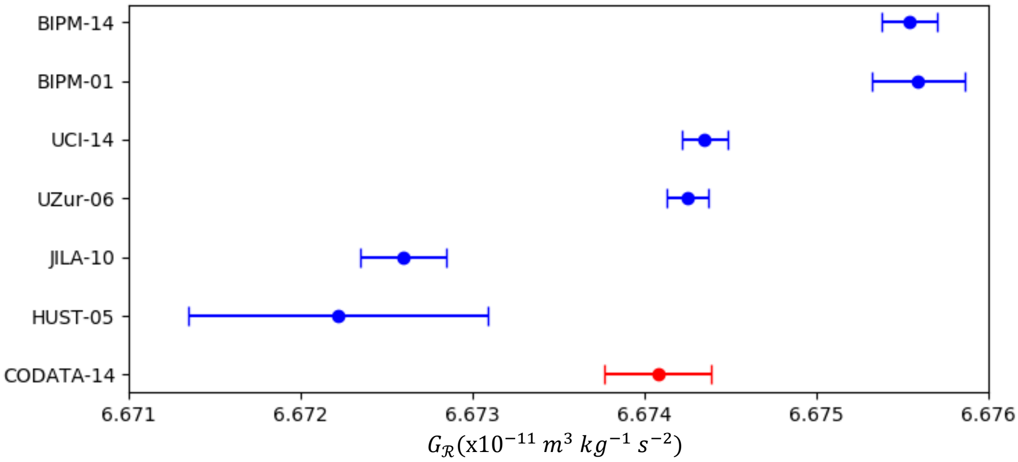

Figure 2. Six of G values among those that were adopted in the CODATA 2014 recommended value.

A one-way ANOVA test was performed on these precision measurements, resulting in an F-statistic of 302.089 and a p-value of 0.000, which indicates strong evidence against the null hypothesis. This signifies that there is a significant difference in the variances of these measurements. Despite the small relative uncertainty in the measurements, the significant differences in their outcomes that puzzled scientists [1] can be attributed to the differences in the curvature of the bulk at the time that the measurements were conducted, as stated in Equation (6), owing to varied positions of the Moon and other nearby planets.

3. Emergence of Mass

Analogous to the constant bulk's modulus, $-\mathcal{F}_{\lambda\rho}\mathcal{F}^{\lambda\rho}/4\mu_0$, the curvature of the bulk, including that which is conformal, $\mathcal{R}_{\mu\nu}\tilde{g}^{\mu\nu}$, and induced by a celestial object, $R_{\mu\nu}g^{\mu\nu}$, can be considered constant regarding quantum fields, $L_{\alpha\beta}L^{\alpha\beta}/2\chi_0$. Consequently, the action in Equation (3) can be extended in terms of quantum waves, as follows

$$S = \int_B \left[\frac{-\mathcal{F}_{\lambda\rho}\tilde{g}^{\lambda\gamma}\mathcal{F}_{\gamma\alpha}\tilde{g}^{\rho\alpha}}{4\mu_0}\right]\sqrt{-\tilde{g}}\int_C \left[\frac{R_{\mu\nu}g^{\mu\nu}}{\mathcal{R}_{\mu\nu}\tilde{g}^{\mu\nu}}\right]\sqrt{-g}\int_Q \left[\frac{p_\mu p_\nu q^{\mu\nu}}{\pi_\mu\pi_\nu g^{\mu\nu}} + \frac{L_{\alpha\beta}q^{\alpha\lambda}L_{\lambda\gamma}q^{\beta\gamma}}{2\chi_0\mathcal{L}_{\mu\nu}g^{\mu\nu}}\right]\sqrt{-q}\,\vartheta^2 d^{12}\sigma \quad (7)$$

where $L_{\alpha\beta}L^{\alpha\beta}/2\chi_0$ are the Lagrangian densities of two entangled quantum fields that are regarded as 4D relativistic quantum clouds of a metric $q_{\mu\nu}$ and four-momentum $p_\mu p^\nu$, respectively, χ_0 is a proportionality constant and ϑ^2 is a dimensional-hierarchy factor; while $\pi_\mu\pi^\nu$ are the four-momentum of the vacuum energy density of a Lagrangian density $\mathcal{L}_{\mu\nu}g^{\mu\nu}$. By applying the principle of stationary action, separating the two entangled quantum clouds and utilizing the dimensional analysis, give

$$p_\mu - \frac{1}{2}p^\nu q_{\mu\nu} - p^\nu\tilde{q}_{\mu\nu} - (J^\mu A_\mu - \frac{1}{2}J^\mu A^\nu\zeta_{\mu\nu}) + \frac{p^\nu}{\pi^\nu}(\mathcal{J}^\mu\mathcal{A}_\mu - \frac{1}{2}\mathcal{J}^\mu\mathcal{A}^\nu\varsigma_{\mu\nu}) = \frac{\hbar G_{\mathcal{R}}}{2c^2 g_R}\mathcal{T}_\mu \quad (8)$$

where $\hbar$ is Planck constant, J^μ is the four current flux from the quantum cloud boundary, g_R is the gravitational field strength of its parent cloud-world and $\mathcal{T}_\mu$ denotes the energy density and flux of the quantum cloud of a deformed configuration as shown in Figure 3, where $\mathcal{T}_n$ is the traction vector on the inner surface S_i and n is the unit normal vector.

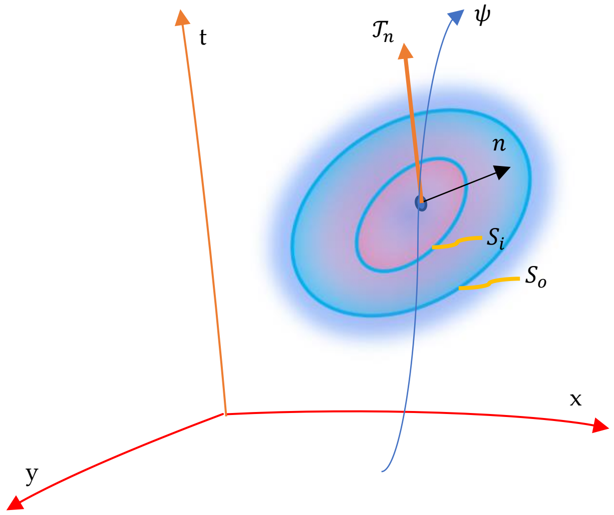

Figure 3. The deformed configuration of the 4D relativistic quantum cloud (quantum field) of metric $q_{\mu\nu}$ along its travel and spin through the curved background of metric $\tilde{q}_{\mu\nu}$. The configuration is given by, S_i, the inner surface of the quantum cloud that separates its continuum into two portions and encloses an arbitrary inner volume while S_o is the outer surface of the cloud's boundary.

As the gravitational field strength of the cloud-world of mass M and at curvature radius R is $g_R = MG_{\mathcal{R}}/R^2$, a plane wavefunction, $\psi = Ae^{-i(\omega t - kx)}$, can be expressed by utilizing Equation (8) as $\psi = Ae^{-i(R^2/2Mc^2)\,\mathcal{T}_\mu x^\mu}$, consequently, the quantized field equations are

$$i\hbar\gamma^\mu\partial_\mu\psi - \frac{1}{2}i\hbar\gamma^\mu\partial^\nu(q_{\mu\nu} + 2\tilde{q}_{\mu\nu})\psi - (J^\mu A_\mu - \frac{1}{2}J^\mu A^\nu\zeta_{\mu\nu})\psi + (\mathcal{J}^\mu\mathcal{A}_\mu - \frac{1}{2}\mathcal{J}^\mu\mathcal{A}^\nu\varsigma_{\mu\nu})i\hbar\gamma^\mu\partial^\nu\psi/\pi^\nu = \frac{1}{2}\frac{\hbar}{x^\mu}R\partial_R\psi \quad (9)$$

where $\gamma^\mu\partial^\nu\psi/\pi^\nu$ signifies the spin-spin correlation of conventional, $\gamma^\mu\partial^\nu\psi$, and vacuum energy fields, π^ν. Although $\pi_\mu\pi^\nu$ are the two entangled fields signifying the momentum of vacuum energy density that could be of a total zero spin, π^ν signifies a single field of vacuum energy of a possible spin, which can be conjectured as an analogue of a part of the singlet Cooper pair of a total zero spin. This reveals that the spin-spin correlation and the bulk's boundary interactions, $\mathcal{J}^\mu\mathcal{A}_\mu$, contribute to the emergence of mass.

4. Geometric-Abstraction Reduction

The field equations in Equation (8) with implicit bulk boundary term in [6] are

$$\hat{p}_\mu\psi - \frac{1}{2}\hat{p}^\nu\xi_{\mu\nu}\psi - (J^\mu A_\mu - \frac{1}{2}J^\mu A^\nu\zeta_{\mu\nu})\psi = \frac{\hbar G_{\mathcal{R}}}{2c^2 g_R}\hat{\mathcal{T}}_\mu\psi \quad (10)$$

where $\xi_{\mu\nu} = q_{\mu\nu} + 2\tilde{q}_{\mu\nu} - 2\bar{\bar{q}}_{\mu\nu}$ is the conformally transformed metric tensor counting for the quantum cloud's metric, $q_{\mu\nu}$, in addition to contributions from intrinsic and extrinsic curvatures of the bulk based on its metrics $\tilde{q}_{\mu\nu}$ and $\bar{\bar{q}}_{\mu\nu}$ (intrinsic-equivalent) respectively. Similarly, $\zeta_{\mu\nu} = e_{\mu\nu} + 2\tilde{e}_{\mu\nu} - 2\bar{\bar{e}}_{\mu\nu}$ is the conformally induced metric on the quantum cloud boundary. From Equation (10), the expected value of the quantum cloud's volume is $V = \hbar G_{\mathcal{R}}/cg_R$. This reveals that the quantum cloud's volume is quantized and is reliant on the gravitational strength of the parent cloud-world. By quantizing field equations as

$$i\hbar\gamma^\mu\partial_\mu\psi - \frac{1}{2}i\hbar\gamma^\mu\partial^\nu\eta_{\mu\nu}\psi - (J^\mu A_\mu - \frac{1}{2}J^\mu A^\nu\zeta_{\mu\nu})\psi = \frac{\hbar G}{2c^2 g}\mathcal{T}_\mu\psi \quad (11)$$

The quantized field equations can be utilized to reproduce quantum electrodynamics by using an undeformed configuration of the quantum cloud given by the Minkowski metric, $q_{\mu\nu} \to \eta_{\mu\nu}$, of metric signature $(+,-,-,-)$ and using G as a Newtonian present value. For a single electron of mass m and by considering it as having the same properties from all directions, the stress-energy tensor of the quantum cloud is then $\mathcal{T}_\mu = mc^2/V = mgc^3/\hbar G$. Accordingly, the quantizing field equations are

$$i\hbar\gamma^\mu\left(\frac{\partial_t}{c} + \vec{\nabla}\right)\psi - \frac{1}{2}i\hbar\gamma^\mu\left(\frac{\partial_t}{c} - \vec{\nabla}\right)(1,-1,-1,-1)\psi - (J^\mu A_\mu - \frac{1}{2}J^\mu A^\nu\zeta_{\mu\nu})\psi = \frac{1}{2}mc\psi \quad (12)$$

By applying the same metric approach for the boundary term as follows

$$\frac{1}{2}i\hbar\gamma^\mu\left(\frac{\partial_t}{c} + \vec{\nabla}\right)\psi - \frac{1}{2}e\bar{\psi}\gamma^\mu\psi A_\mu\psi = \frac{1}{2}mc\psi \quad (13)$$

where $J^\mu = e\bar{\psi}\gamma^\mu\psi$ is the four-current density, and e is the charge of a single electron. Equation (13) can be reformatted to

$$i\hbar\gamma^\mu\partial_\mu\psi - mc\psi = e\gamma^\mu A_\mu\psi \quad (14)$$

which resembles the Dirac equation and the interaction with the electromagnetic field.

5. Conclusions and Future Experiment Recommendations

To date, about three hundred experiments have attempted to determine the value of $G_{\mathcal{R}}$, with many of them being precision measurements. However, the significant inconsistencies in their outcomes have made it unfeasible to reach a consensus on an exact value, which puzzled scientists.

The derived interaction field equations demonstrated the dependency of $G_{\mathcal{R}}$ on the background curvature and the associated field strength of vacuum energy. Additionally, the equations revealed that the boundary interactions of conventional and vacuum energy densities and their spin-spin correlations contribute to the emergence of mass.

To achieve consistent $G_{\mathcal{R}}$ measurements, it is necessary to consider the positions of the Moon and other nearby planets, as they can influence the curvature of the background. Variations in background curvature can significantly contribute to observed differences in the precision measurements according to the derived interaction field equations, and it is essential to determine the extent of their impact on measurement variability. Future precision experiments should aim to address this issue of inconsistent $G_{\mathcal{R}}$ measurements by accounting for the influence of these celestial bodies. One simple approach could be to conduct measurements twice, with one set taken when the Moon is on the horizon and another set taken when it is on the opposite side of the Earth. Finally, to ensure higher consistency in the measurements, the positions of nearby planets can also be considered.

Conflicts of Interest: The author declares no conflicts of interest.

References

[1] Xue C, Liu J P, Li Q, Wu J F, Yang S Q, Liu Q, Shao C G, Tu L C, Hu Z K and Luo J 2020 Precision measurement of the Newtonian gravitational constant *Natl. Sci. Rev.* **7** 1803–17

[2] Rosi G, Sorrentino F, Cacciapuoti L, Prevedelli M and Tino G M 2014 Precision measurement of the Newtonian gravitational constant using cold atoms *Nat. 2014 5107506* **510** 518–21

[3] Schlamminger S 2018 Gravity measured with record precision *Nat. 2021 5607720* **560** 562–3

[4] Gibney E 2014 Rivals join forces to nail down Big G. Metrologists meet to design the ultimate gravitational-constant experiment *Nature* **514** 150–1

[5] Schlamminger S 2014 Fundamental constants: a cool way to measure big G *Nature* **510** 478–80

[6] Al-Fadhli M B 2022 Celestial and Quantum Propagation, Spinning, and Interaction as 4D Relativistic Cloud-Worlds Embedded in a 4D Conformal Bulk: From String to Cloud Theory. Preprints 2020, 2020100320. https://doi.org/10.20944/preprints202010.0320.v9.

[7] Kozameh C, Newman E, gravitation K T-G relativity 1985 Conformal Einstein spaces *Springer*

[8] Quinn T, Parks H, Speake C and Davis R 2013 Improved determination of G using two methods *Phys. Rev. Lett.* **111** 101102

[9] Quinn T J, Speake C C, Richman S J, Davis R S and Picard A 2001 A New Determination of G Using Two Methods *Phys. Rev. Lett.* **87** 111101

[10] Newman R, Bantel M, Berg E and Cross W 2014 A measurement of G with a cryogenic torsion pendulum *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **372**

[11] Schlamminger S, Holzschuh E, Kündig W, Nolting F, Pixley R E, Schurr J and Straumann U 2006 Measurement of Newton's gravitational constant *Phys. Rev. D - Part. Fields, Gravit. Cosmol.* **74** 082001

[12] Parks H V. and Faller J E 2010 Simple pendulum determination of the gravitational constant *Phys. Rev. Lett.* **105** 110801

[13] Hu Z K, Guo J Q and Luo J 2005 Correction of source mass effects in the HUST-99 measurement of G *Phys. Rev. D - Part. Fields, Gravit. Cosmol.* **71** 127505

[14] Mohr P J, Newell D B and Taylor B N 2016 CODATA recommended values of the fundamental physical constants: 2014 *Rev. Mod. Phys.* **88** 035009