

Accounting Orbital Precession with a Higgs-Like Physical Gravity-Field Model

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Abstract

We posit the gravitational field to be a direct manifestation of a flat-space physical entity, whose properties are only partially known. Specifically, herein we first derive that (i) motion of an object along a non-isometric field gradient results in a commensurate change $[m_{\psi}(r)]$ to its inertial mass, and (ii) that its field potential is indicative of the refractive index of the medium, hence needing a corrective potential scaling. By applying these properties through first principles, for a weak-field planetary assumption we derive a rosette equation that reproduces the General Relativity (GR) precession result exactly. We further consider strong-field stellar precession, such as S62, where observational data is still emergent but both the proposed theory and exact-GR solutions are comparable—an area for further study. The overall solution has no impact on established artefacts around light-bending observations at these scales. This physical framework draws on the mechanism by which the Higgs field imparts mass to elementary particles, positing an analogous, partially-characterized gravitational field as a step toward a more unified physical account of gravity.

Keywords

Perihelion Precession, General Relativity, Inertial Mass, Modified Inertia, Gravitational Field, Rosette Orbit, S-Cluster Stars, S62

1. Introduction

The periapsis zone of orbits and trajectories¹ that move close proximity to central mass, is an interesting arena to explore GR and alternative theories that address

¹Interstellar object—Oumuamua, showed post-perihelion gravitational acceleration which was atypical in nature [1].

deviations beyond Kepler-Newton expectations. The classical example was the case of mercury: with its close proximity to sun and large eccentricity, it needed a corrective theory to its gap in observation. Historically, Mercury's perihelion precession was accounted for [2] in large part ($\sim 93\%$) by the remaining-planets, and to a smaller albeit precise part (*i.e.*, 7% or 42" per century) by GR. The theoretic fitment extends to all planetary observation *i.e.*, in the weak-gravitational field domain. Similar observations are emerging at galactic scale from stars orbiting close to the large central mass of our Milky Way: Sagittarius A* (Sgr-A*) with mass ~ 4 million $M_{\odot}$. The star S62, for example, demonstrates a highly elliptical orbit ($e = 0.976$), with a prograde *Schwarzschild Precession* (SP) order of $\delta\phi = 74.70 \pm 31.00'$ per orbit [3]. With newer data emerging from stellar cases, yet again GR is able to achieve the fitment significantly accurate [4].

Classically perfect closed loop elliptic orbit is derived from Keplerian laws with the basis of first-principle, *i.e.*, energy conservation or Euler-Lagrange equations. However, for the expected precession gap, theories often resort to Post-Newtonian parameters (PPN) and mathematical perturbations to settle into a final equation for $\delta\theta$. GR derives the following contribution to angular skew owing to space-time warpage at close proximity to central mass [5] [6]. For weak-field approximation it is,

$$\delta\theta_{GR} = \frac{6\pi GM}{ac^2(1-e^2)} \quad (1)$$

where M is the central mass, c is speed of light, a is the semi-major axis and e eccentricity.

2. Influence from Gravity Vector Field on Mass

Consider an object of mass m_A at rest relative to the large overarching reference frame of gravitational potential-well in which it resides. Here, the term *large* refers to an assumption that any perturbations at far-off distances are not significantly influencing the shape of the potential-well locally. With regard to the local gravitational potential scalar U and the field gradient vector V , we could have one of the two scenarios:

Scenario i) nonzero gravity potential U but (hypothetically²) with no gradient in any specific direction *i.e.*, $V = 0$. In this case, the definition and perception of mass is through an external force F required to accelerate by a . The force was necessary to overcome the inertia of rest. Hence the inertial mass m_A . The frame of reference against which the inertial-rest existed has been debatable: Newton presumed it to be an absolute reference in empty-space. Critics including Ernst Mach, contested that such frame would be abstract and arbitrary, if not considering inertia as an effect from all the masses in the universe [7].

Scenario ii) nonzero field vector V pointing radially toward nearest massive body. Here, there is an inherent "force" on m_A toward the gradient (∇U). His-

²We can consider the case of $V \rightarrow 0$ as approximation in the intergalactic voids.

torically, this “force” has had two important perspectives: First, as quantified by Newton’s inverse-square law that accompanied with an acknowledgment that the origins of such a force is yet unknown³; Second—by Einstein’s GR theory attributing the “force” as an artefact of space-time curvature along the direction of the gradient; and further that mass involved with this force is *equivalent* to inertial mass.

We could define a physical reference-frame around m_A in terms of gravitational field gradient contour in the background of a given body. Here every other mass has some contribution to the contour as defined through superposition of fields (Refer **Figure 1**). Though such a reference frame is dynamic with a gradual changing contour at stellar scales, practically it can still serve the purpose of static reference. In some sense, such a reference frame bridges the Newton’s hypothetical *empty-space as reference-frame* to that stated by Mach as involving the *effects from all the masses in the universe*. More recent proposals [8] have treated gravity itself as an emergent, thermodynamic-like phenomenon of an underlying physical substrate, rather than a fundamental geometric field as in GR. The case of ever-permeating Higg’s field [9] which won the coveted Nobel prize with the detection of Higg’s-boson signature, further drives the point: fields are the apt canonical representations of physicality.

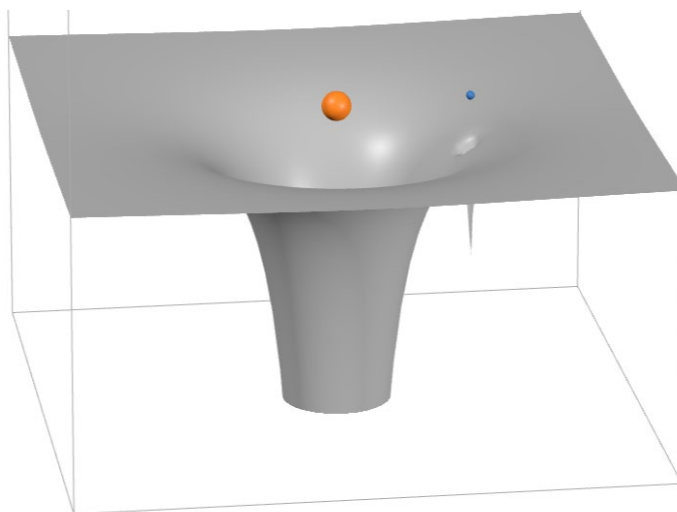


Figure 1. Gradient-well ($1/r^2$) can be represented similar to potential-well ($1/r$). The main difference being that the slope here depicts the vector gradient general direction and its absolute height depicts the magnitude. The smaller mass m_A shown in blue dot has its own local gradient-well that merges with the overarching field following superposition of the fields.

We posit that the origin of inertia during motion of a body emanates from interaction of local gradient-well (indistinguishable from the body itself) with the overarching gradient frame. Since the matter and the gradient-well are insepara-

³A humble “Hypotheses non fingo”, as he stated.

ble, gravitational attraction between masses is indistinguishable from tendency of smaller gradient-well to merge into larger one. Note that an object at motion along an isometric-gradient path (e.g. constant radius circular orbit) would therefore not experience change in its inertial mass.

The broader strategy of modifying inertia (rather than the force law) to account for otherwise anomalous dynamics has precedent in the literature. For instance, in the modified-inertia program of quantised inertia [10] [11], alongside the more widely known modified-gravity alternatives such as MOND [12] and Scalar-Tensor-Vector Gravity [13], which similarly seek to explain dynamical anomalies. Any competing theory needs to address the most prominent tests and solutions that GR provides. Apart from precession, this includes bending of light per Eddington observations, Shapiro delay and Gravitational Redshift. Alternative theories with material medium [14] [15] do address light bending very well. In this proposal we shall simultaneously use the posits of inertia and light deflection together as both are crucial parts of a holistic theory.

3. Inertial-Mass $\tilde{m}(r)$

In the scenario of kinetic interaction where local gradient-well (radial component) moves toward epicenter of overarching-well, it can be demonstrated to cause additional inertial mass $m_{\psi}(r)$. Consider bounded orbit with farthest distance (aphelion A) under the influence of central force field as in **Figure 2**. For a hypothetically stationary mass (in this field frame), the rest-mass m_A is not influenced; therefore potential-energy assessment is not altered through inertia.

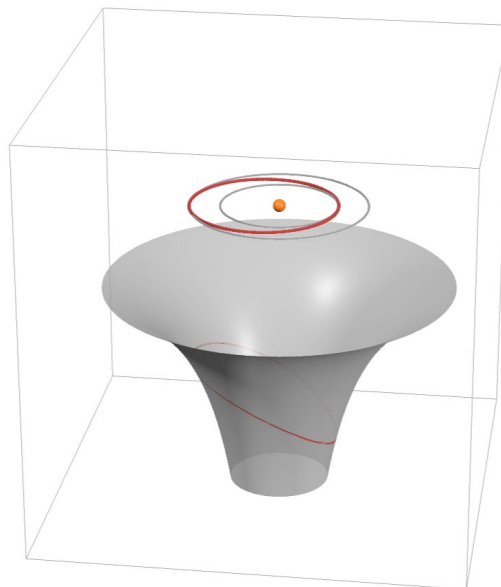


Figure 2. The inner periapsis circle (r_p) and outer apoapsis circle (r_a) in Grey are concentric about the focus where the star/sun is shown in orange. The Grey surface is a figure of revolution (Gabriel's horn) about the function $\propto -1/r$ from the gravitational potential (U). The actual elliptic orbit and its projection on the horn is shown in red.

The magnitude of inertial mass $m_\psi(r)$ is modeled to increase as it falls closer to central force field. That is, additional energy gained by the body, is reflected in its kinetics with $m(r)$.

$$\Delta E = -\frac{GMm(r)}{r^2}dr$$

For a small radial component dr , let dm be the increase in inertial mass.

$$(dm)c^2 = -\frac{GMm(r)}{r^2}dr$$

For any r along the orbit, the total inertial mass gained from starting reference m_A would be:

$$\begin{aligned}\int_{m_A}^{m(r)} \frac{1}{m(r)} dm &= -\frac{GM}{c^2} \int_A^r \frac{1}{r^2} dr \\ \ln\left(\frac{m(r)}{m_A}\right) &= -\frac{GM}{c^2} \left(-\frac{1}{r}\right) \Big|_A^r \\ \frac{m(r)}{m_A} &= e^{\frac{GM}{c^2} \left(\frac{1}{r} - \frac{1}{A}\right)}\end{aligned}$$

From Taylor expansion

$$m(r) \approx m_A \left[1 + \frac{GM}{c^2} \left(\frac{1}{r} - \frac{1}{A} \right) \right]$$

Therefore, denoting factor $F_k = GM/c^2$ as associated with Kinetic Energy, we have:

$$\tilde{m} = m(r) = m_A + m_\psi(r) \quad (2)$$

where,

$$m_\psi(r) = m_A F_k (1/r - 1/A) \quad (3)$$

Note that, if it was a perfect circular orbit with $r = A$, then $m_\psi = 0$ as posited for isometric path along the gradient-well.

There are some immediate implications of this function beyond treating additional inertial mass as function varying between Apogee A ($m_A + 0$) and Perigee P ($m_A + m_\psi(P)$). If Equation (3) were true, all the current well-known mass assessment are position dependent value locked to a tiny variation range within their orbital motion. Recognizing F_k relates to Schwarzschild radius (*i.e.*, $R_s/2$), and given its small value as compared to distance A , this results in tiny mass change. However, we could assess the hypothetic absolute range of mass for this matter between a shortest radius, say $n \times R_s (\ll A)$ to farthest at ∞ . This evaluates to range from $(100/2n)\%$ of m_A gain at closest proximity, to lowest after losing $(R_s/2A)\%$ of m_A . Therefore, there is no universal intrinsic value for mass in this proposition. Thus, m_A is considered as a base reference value of unperturbed intrinsic mass contextual to a given orbit. Avoiding digression, this

study would be of further interest to its implications in the trajectories of rare visitors such as interstellar objects.

4. Potential Scaling Due to Media's Refractive Index

Attributing refractive index $n(r)$ to flat space has been well-established formulation that has stood the test of time since Eddington's full-bending observations of star-light [16] [17]. This is given as,

$$n(r) = 1 + \frac{2GM}{rc^2} \quad (4)$$

Supposing that the elementary nature and properties of such a medium are unknown, we posit that the Gravitational potential is exact a manifestation density of physical medium. Therefore we need to account for refractive-index into this manifest. Accordingly the potential scalar U , needs to be multiplied with $n(r)$. However, to be able to reflect the contribution of the factor that scales with $(1/r)$ and carry it through the derivation of precession, we attribute the factor F_u to represent $2GM/c^2$. Thus, we have $n(r) = 1 + F_u/r$ and the scaled potential:

$$\tilde{U}(r) = U(r)n(r) = U(r)\left(1 + \frac{F_u}{r}\right) \quad (5)$$

Therefore Potential Energy (E_u) associated with this is: $U(r)(1 + F_u/r)m_A$. Note that the mass m_A is not the one that is scaled, it is the potential.

5. Deriving Rosette from First Principles

The total energy after plugging Equation (2) and Equation (5) as scaled Kinetic mass and scaled Potential respectively, is:

$$E_T = E_k + E_u = \frac{1}{2}\tilde{m}v^2 + \tilde{U}(r)m_A \quad (6)$$

Defining a constant grouping parameter as, $C_A = 1 - \frac{F_k}{A}$

We transform the orbital angular momentum conservation (L) equation using Binet's variable ($u = 1/r$)

$$L = m_A \left[1 + F_k \left(\frac{1}{r} - \frac{1}{A} \right) \right] r^2 \dot{\theta} = m_A (C_A + F_k u) \frac{1}{u^2} \dot{\theta}$$

Isolating the angular coordinate velocity ($\dot{\theta}$) yields

$$\dot{\theta} = \frac{Lu^2}{m_A(C_A + F_k u)}$$

Applying chain rule, $\left(\dot{r} = -\frac{1}{u^2} \frac{du}{d\theta} \dot{\theta} \right)$, the radial velocity is,

$$\dot{r} = -\frac{L}{m_A(C_A + F_k u)} \frac{du}{d\theta}$$

$$v^2 = \dot{r}^2 + r^2 \dot{\theta}^2 = \frac{L^2}{m_A^2 (C_A + F_k u)^2} \left[\left(\frac{du}{d\theta} \right)^2 + u^2 \right]$$

Equation (6) is now,

$$E_T = \frac{1}{2} m_A (C_A + F_k u) \cdot \frac{L^2}{m_A^2 (C_A + F_k u)^2} \left[\left(\frac{du}{d\theta} \right)^2 + u^2 \right] - GMm_A u - GMm_A F_u u^2$$

Rearranging,

$$\left(\frac{du}{d\theta} \right)^2 = \frac{2m_A}{L^2} (E_T + GMm_A u + GMm_A F_u u^2) (C_A + F_k u) - u^2 \quad (7)$$

This results in cubic equation in u , where the (u^3) term is highly suppressed $(F_k F_u \propto 1/c^4)$ and can be dropped for weak-field domains to get:

$$\left(\frac{du}{d\theta} \right)^2 = -\beta^2 u^2 + \gamma u + \zeta$$

where,

$$\beta^2 = 1 - \frac{2GMm_A^2}{L^2} (C_A F_u + F_k)$$

$$\gamma = \frac{2GMm_A^2}{L^2} \left(C_A + \frac{E_T F_k}{GMm_A} \right)$$

$$\zeta = \frac{2C_A m_A E_T}{L^2}$$

Integrating both sides, we get:

$$\int d\theta = \int \frac{du}{\sqrt{-\beta^2 u^2 + \gamma u + \zeta}}$$

$$\theta - \theta_0 = \frac{1}{\beta} \arccos \left(\frac{2\beta^2 u - \gamma}{\sqrt{\gamma^2 + 4\beta^2 \zeta}} \right)$$

Defining periapsis to be the $\theta_0 = 0$ reference of cylindrical coordinates and inverting $u(\theta) = 1/r$, we arrive at rosette contour:

$$r(\theta) = \frac{l}{1 + e \cos(\beta\theta)} \quad (8)$$

where e (eccentricity) is,

$$e = \sqrt{1 + \frac{4\beta^2 \zeta}{\gamma^2}}$$

and semi-latus l is,

$$l = \frac{2\beta^2}{\gamma} \quad (9)$$

The Equation (8) defines a rosette contour. A precessing “elliptical orbit” is mathematically best described as continually looping rosette (**Figure 3(b)**) rather than closed-ellipse with one secular advance per orbit (**Figure 3(a)**). The derived equation differs from perfect Keplerian ellipse where there is no precession term ($\beta = 1$). If β were to be exactly 1, this would imply (from Equation (10)), that

$A = \frac{R_s}{3}$ which is not practical orbit. Therefore, practically β should always be less than 1: *Every eccentric orbit must precess.*

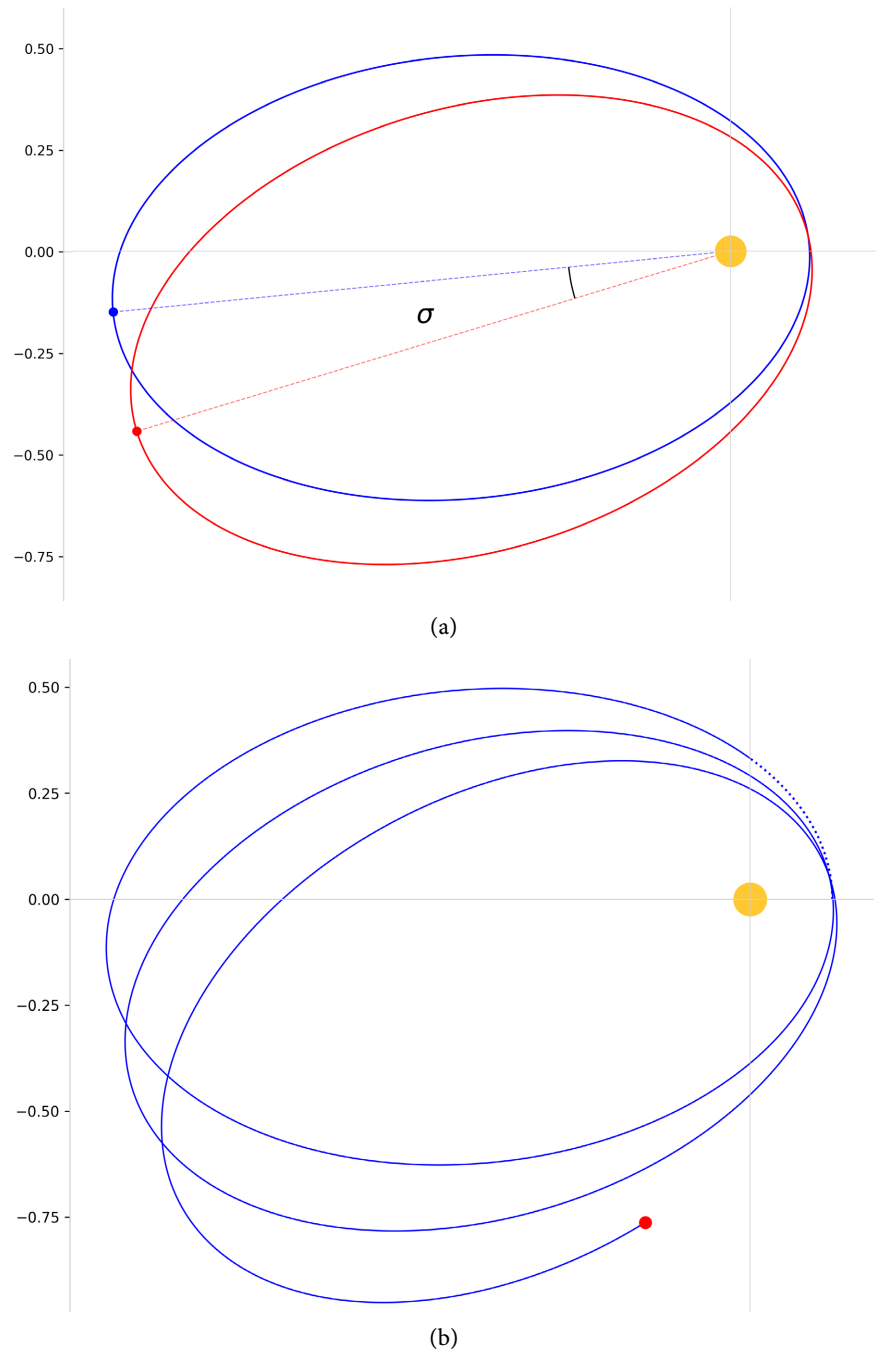


Figure 3. (a) A closed ellipse tilting by σ , as against (b) continually precessing rosette contour.

Another fallout relates to second focal point in Keplerian elliptic as a conic section. Among its two focii, conventionally one represents the point where the central mass is tethered, but second has had no physical significance. However, as per

above assessment there should be no perfect elliptic orbit rather it is always a rosette contour. Though a minor aspect, it is of physical significance as it undefines the second focal point mathematically. Therefore: *All eccentric orbits have only one fixed focal point—its central mass.*

6. Simplifying β for Weak-Field Assumptions

The present GR treatment, while accurately accounting expected precession angle, trades the derivation with PPN perturbation approach and involves oscillating harmonic terms even with weak-field assumption. For instance, recent literature has raised related concerns [18] that exist in this area. In the presented theory, the distribution of precession is a continuum as defined by β . Therefore, we simplify β further based on factors native to the proposed theory.

$$\text{Given that, } l = \frac{2\beta^2}{\gamma} \Rightarrow \gamma = \frac{2\beta^2}{l}$$

$$\text{We can write, } e^2 = 1 + 4\beta^2 \zeta \left(\frac{l}{2\beta^2} \right)^2 = 1 + \frac{l^2 \zeta}{\beta^2}$$

Substituting the explicit definitions of ζ and γ into the ratio $\frac{\zeta}{\gamma}$ to isolate the total energy (E_T):

$$\frac{\zeta}{\gamma} = \frac{\frac{2C_A m_A E_T}{L^2}}{\frac{2GMm_A^2}{L^2} \left(C_A + \frac{E_T F_k}{GMm_A} \right)} = \frac{C_A E_T}{GMm_A \left(C_A + \frac{E_T F_k}{GMm_A} \right)}$$

Solving this system directly links the total orbital energy parameter E_T strictly to the geometric shape parameters (l, e):

$$\frac{E_T}{GMm_A} = \frac{C_A (e^2 - 1)}{2C_A l + F_k (1 - e^2)}$$

The semi-latus rectum l acts as an algebraic bridge: by writing L^2 in terms of l and E_T , we create a pathway where substituting the energy equation automatically causes the dynamic momentum terms to vanish, leaving a purely geometric result

$$\beta^2 = \left[1 + \frac{(C_A F_u + F_k) [2C_A l + F_k (1 - e^2)]}{C_A^2 l^2} \right]^{-1}$$

$$\beta = \frac{1}{\sqrt{1 + \frac{2(C_A F_u + F_k)}{C_A l} + \frac{F_k (C_A F_u + F_k) (1 - e^2)}{C_A^2 l^2}}}$$

Weak-Field Approximation ($F \ll l$): Performing a standard first-order binomial expansion on this geometric expression isolates the leading-order physical behavior:

$$\beta \approx 1 - \frac{C_A F_u + F_k}{C_A l}$$

$$\beta \approx 1 - \left(\frac{F_k}{C_A l} + \frac{F_u}{l} \right) \quad (10)$$

The anomalous precession per revolution ($\delta\theta$) is the spatial advance past a standard 360° orbit:

$$\delta\theta = \frac{2\pi}{\beta} - 2\pi$$

weak-field binomial expansion $(1-x)^{-1} \approx 1+x$, the inverse of β evaluates to

$$\frac{1}{\beta} \approx 1 + \left(\frac{F_k}{C_A l} + \frac{F_u}{l} \right)$$

$$\delta\theta \approx \frac{2\pi}{a(1-e^2)} \left(\frac{F_k}{C_A} + F_u \right)$$

$$\frac{1}{C_A} = \left(1 - \frac{F_k}{A} \right)^{-1} \approx 1 + \frac{F_k}{A}$$

The orbital precession per orbit

$$\delta\theta = \frac{2\pi}{a(1-e^2)} \left[F_k + F_u + \frac{F_k^2}{A} \right] \quad (11)$$

The F_k^2 term has to be dropped aligning with our weak-field approximation already factored earlier. Substituting F_k and F_u ,

$$\delta\theta_{\text{mediaWF}} = \frac{6\pi GM}{ac^2(1-e^2)} \quad (12)$$

In the preceeding Equation (11) it is worth pondering about the factors F_k and F_u : If we set aside the F_k^2 term ($\propto 1/c^4$) which we shall analyze in strong-field results, the sum ($F_k + F_u$) is $3 \times GM/c^2$. It can be re-evaluated from first principles that any solution that satisfies the sum is sufficient to meet the GR expectation. That is, coefficient of GM/c^2 in (F_k, F_u) respectively, could for example be (0, 3) or (1.5, 1.5) or (2.5, 0.5) ... However, the only set of value that also have exact association with first-principle is (1, 2). The F_k is derived independently here from the inertial-mass mechanism, while F_u is posited directly from the well-established refractive-index relation.

For space filled with such a media, $\delta\theta_{\text{mediaWF}}$ is an exact solution that GR also derives with the weak-field assumptions. As this is same as Equation (1), therefore there is no difference to the precession gap as addressed by GR versus the proposed theory. This is true for mercury and all other planets.

7. Strong-Field Deviation

We dropped the $(1/c^4)$ term in earlier Equation (7). However, in strong-fields with million times $M_\odot$, highly eccentric orbits and close proximity comparable to AU, the term (δ) cannot be completely ignored.

$$\left(\frac{du}{d\theta}\right)^2 = P(u) = \delta u^3 - \beta^2 u^2 + \gamma u + \zeta, \quad \delta = \frac{2GMm_A^2 F_k F_u}{L^2} \quad (13)$$

$$\begin{aligned} \frac{d^2 u}{d\theta^2} + u &= u + \frac{P'(u)}{2} \\ &= \frac{3F_k F_u GMm_A^2}{L^2} u^2 + \frac{2GMm_A^2 (AF_k + AF_u - F_k F_u)}{AL^2} u + (\text{const.}) \end{aligned}$$

$$u_0(\theta) = \frac{1}{a(1-e^2)}(1 + e \cos \theta)$$

$$c_1 = \frac{1}{\pi} \int_0^{2\pi} \text{RHS}(u_0(\theta)) \cos \theta d\theta$$

$$\delta\theta_{\text{orbit}} = \frac{2\pi}{a(1-e^2)}(F_k + F_u) + \frac{4\pi G^2 M^2 (e+2)}{a^2 c^4 (1-e^2)^2}$$

$$\delta\theta_{\text{mediaSF}} = \frac{6\pi GM}{ac^2(1-e^2)} \left[1 + \frac{2GM(e+2)}{3ac^2(1-e^2)} \right] \quad (14)$$

The $\delta\theta_{\text{mediaSF}}$ differs from GR weak-field Equation (1) by the extra term on RHS with strong bearing on eccentricity e and proximity a .

8. Results and Discussion

No new precession results are required for $\delta\theta_{\text{mediaWF}}$ as it is identical to GR. Hence we apply the $\delta\theta_{\text{mediaSF}}$ to compare the resulting values (Refer **Table 1**) for each of the planet and compare the GR established/expected value. The orbital parameters used in the planetary data table originate from public planetary ephemerides compiled and maintained by space agencies NASA [19]. On identical planetary parameter data, the proposed theory matches the GR-expected values to high degree of accuracy. The small deviation is of interest to assess if this is factually found with more recent higher accuracy observations.

Table 1. Perihelion precession: GR-predicted vs. proposed media theory, $F_k = GM/c^2$, $F_u = 2GM/c^2$.

Planet	$\delta\theta_{\text{GR}}$ (arcsec/century)	$\delta\theta_{\text{mediaSF}}$ (arcsec/century)	Deviation (arcsec/century)
Mercury	42.977472	42.977473	1.682×10^{-6}
Venus	8.625121	8.625121	1.575×10^{-7}
Earth	3.838508	3.838508	5.095×10^{-8}
Mars	1.350821	1.350821	1.232×10^{-8}
Jupiter	0.062252	0.062252	1.617×10^{-10}
Saturn	0.013543	0.013543	1.919×10^{-11}
Uranus	0.002375	0.002375	1.667×10^{-12}
Neptune	0.000771	0.000771	3.391×10^{-13}

We also consider high-velocity S-cluster stars (S2, S62, and S4711) orbiting the supermassive black hole Sgr A*. Central mass of Sgr A* is taken as $M = 4.261 \pm 0.012 \times 10^6 M_\odot$, giving a Schwarzschild radius of $R_s \approx 0.0819 \text{ AU}$. These stars orbit in a significantly stronger gravitational field. For example, S62 [3] has an extreme eccentricity ($e = 0.976$) and plunges down to a periapsis distance of just 16 AU from the black hole horizon, its overall relativistic precession rate is enormous (~ 14.1 degrees per century). For the proposed precession theory, this is an important scaling-test in the realm of strong-gravitational field as compared to solar system assessment. Therefore, we compare the strong-field GR-Exact data as well.

Table 2 demonstrates the new theory is aligning well with GR-proposed values. Notwithstanding the relatively larger observational uncertainty, unlike the weak-field solar system the theoretic deviation, for example with S62, reaches a significant value. Given the large error margin for observational data itself at present, this needs to be studied as more accurate data becomes available.

Table 2. Strong-field precession per orbit for Sgr A* S-cluster stars. “Observed” for S2 is $f_{SP} \times \Delta\theta_{\text{GR(1PN)}}$ using the fitted $f_{SP} = 1.10 \pm 0.19$ (GRAVITY Collaboration 2020) [4]—a genuine detection of the precession effect. For S62 and S4711, no such detection yet exists; the quoted values are GR predictions computed from fitted orbital elements (Peißker et al. 2020), not an independent measurement of precession, and are labelled accordingly. GR (Exact) is obtained by direct numerical integration of the exact Schwarzschild cubic orbit equation, without the 1PN truncation. Both deviation columns are far smaller than current observational uncertainty in every case and are not presently distinguishable from zero.

Star	Observed (arcmin/orbit)	GR (1PN)	GR (Exact)	Proposed (strong field)	GR Deviation	New Theory Deviation
S2	13.43 ± 2.32	12.2055	12.2163	12.2100	-1.2097	-1.2161
S62	74.70 ± 31.00	77.3452	77.7855	77.5283	+3.0855	+2.8283
S4711	10.30 ± 1.30	10.6663	10.6744	10.6695	+0.3744	+0.3695

9. Conclusions

We proposed a theory building toward a physical construct for mediating gravity, while acknowledging that the underlying medium’s structural details remain unknown. We derived a generalization for inertial mass from first principles and combined it with the century-old refractive-index formulation of gravitational potential, yielding a rosette solution via classical mechanics—without recourse to PPN perturbation or harmonic terms. A structural consequence of this rosette treatment is that every eccentric orbit precesses, however slightly, and that the second dummy-focus of the classical Kepler ellipse has no physical counterpart in this framework.

Under the weak-field limit relevant to all solar-system planets, the theory reproduces GR’s precession exactly, with $F_k = GM/c^2$ derived independently from the inertial-mass mechanism and $F_u = 2GM/c^2$ posited from the established refractive-index relation—their sum reproducing the GR coefficient ex-

actly, validated here across six orders of magnitude in mass, from Mercury to the Sgr A* S-cluster. Since neither F_k nor F_u modifies $n(r)$ itself, which remains the standard, unaltered form used throughout, light-bending, Shapiro delay, and gravitational redshift—all established consequences of $n(r)$ in the literature—are inherited exactly and require no separate re-derivation here.

We further derived a strong-field extension retaining the previously-dropped higher-order term, and applied it to S2, S62, and S4711. The resulting deviations from GR remain two to three orders of magnitude below current observational precision for all three systems, but S62—with its unusually tight, eccentric orbit—stands out as the most promising candidate for a future test as astrometric precision improves.

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Author Contributions

As sole author, Noor Mubeen is responsible for all aspects of this work: conceptualization, theoretical derivation, data analysis, and manuscript preparation.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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