

Scattering as the Cause of Gravity in Operational Quantum Gravity

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Manuscript version 1.1 · 23 October 2026

Abstract

Operational Quantum Gravity identifies scattering-induced changes of supporting power as the microscopic origin of gravity. Atomic and nuclear charge and current fluctuations throughout both bodies exchange energy with a shared electromagnetic field. Their scattered contributions interfere at each receiver, changing the balanced exchange that sustains its internal state. We connect this distributed material response to the radial supporting-power profile, prove the collective supporting-power scaling for corresponding material equilibria, and connect its spatial variation to recoverable energy and geodesic motion. The material Hamiltonian carries the dispersion interaction into free-fall trajectories with zero proper acceleration. Source and receiver motion enter through the frequencies and field correlations sampled by each body. Two equal planets in a circular orbit demonstrate the resulting mechanics on the calibrated, conservative weak-field branch. Their supporting exchange remains steady while the interaction redirects their motion. The example connects scattering, material response and orbital acceleration in one energy account, with the gravitational coupling supplied by the existing OQG calibration.

Keywords: electromagnetic scattering; supporting power; nuclear response; relative motion; dispersion interaction; geodesic motion; orbital dynamics

1 Introduction

A description of gravity should explain both why matter attracts and how that attraction changes motion. OQG begins with the electromagnetic exchange of matter with its surroundings [1]. Atomic and nuclear charge and current fluctuations throughout each body receive energy and return energy to the shared field. Each planet is therefore a distributed collection of sources and receivers. At equilibrium these positive powers are equal. Their common value is the supporting power; it can change even when the net heating remains zero.

The shared field conveys the influence of one constituent to another. Their induced currents reradiate, and the propagated contributions interfere with the ambient field at other constituents. Changes in either planet alter the exchange sampled by the other through this retarded, coupled response. OQG identifies the resulting adjustment of material energy as the origin of gravitational work and free-fall motion. The storage gradient describes momentum change in fixed comparison standards; the same material response determines clocks and rulers, and its Hamiltonian generates geodesic trajectories. This paper follows that connection through a short orbital demonstration. In the OQG theory, the causal sequence begins with matter and its shared field. The metric subsequently records the clocks, rulers and trajectories produced by that material response.

Let P_0 be a receiver's reference supporting power, held fixed in all spatial derivatives, f its rest-energy and clock-frequency factor, and b its corresponding length factor. The matched common branch has $f = b$; their definitions remain distinct. We use slow motion, weak fields and adjustment through corresponding equilibria. The bare zero-point vacuum is Lorentz invariant. Matter and boundaries define the local ambient spectrum whose reception can depend on relative motion. The nuclear and power scalings use this matched family. Section 3 keeps the clock and ruler factors distinct to display their separate roles in propagation.

2 From scattering to supporting power and work

In the OQG theory, the constituents of both planets participate in a shared electromagnetic field through their coupled energy-storage and exchange response. Their charge and current modes store energy and exchange it with the field. In the low-frequency storage representation, capacitance describes restoring compliance and inductance describes inertia; the nuclear excitation spectrum retains the underlying binding physics. These storage properties, together with the radiative and other damping channels, enter the full frequency-dependent response that determines how each constituent receives and reradiates the field [1, Secs. 2.4, 3.1 and 5.2–5.3]. Each planet therefore acts as both a source and a receiver. Maxwell propagation conveys the scattered amplitudes between constituents, including phase delays and near-field contributions, while repeated scattering couples their responses in both directions. The resulting correlated field changes the balanced supporting exchange. In OQG, that change selects an adjusted material state with a different stored energy. Its spatial variation supplies the energy gradient connected below to mechanical work and geodesic motion.

Scattered intensity alone cannot determine the change in reception because amplitudes interfere before their power is averaged. For a fixed receiver, let u be the reference exchange amplitude, normalized to unit power, and s the total change after all retained scattering. Both include the same spectral and polarization weights. Define $\beta^2 = \langle |s|^2 \rangle$ and $C = \langle u^\dagger s \rangle$, where brackets denote the statistical average and the dagger conjugate transpose. The received-power ratio is

$$Q = \langle |u + s|^2 \rangle = 1 + \beta^2 + 2\text{Re } C, \quad Q < 1 \Leftrightarrow 2\text{Re } C < -\beta^2. \quad (1)$$

This is a general interference criterion: expand the squared total amplitude to obtain the identity and rearrange it to obtain the inequality. It applies to any number of contributing modes. Reduced reception occurs when destructive interference exceeds the added scattered intensity. The resonant two-dipole calculation in [1], using the model of [2], supplies an explicit realization under its stated conditions; the criterion itself retains the collective correlations. The ratio Q compares reception at fixed response; P/P_0 below compares the adjusted material equilibria.

The excitation gaps and transition strengths determine how the nucleus receives and reradiates the shared field. Let ω be angular frequency and χ^R the retarded charge response to voltage. A low-frequency expansion of the conservative part of its inverse defines capacitance C_N and inductance L_N . The corresponding-state theorem in [1] gives $\chi_f^R(f\omega) = f^{-1}\chi_0^R(\omega)$ and $C_{N,f} = C_{N,0}/f$, $L_{N,f} = L_{N,0}/f$. Nuclear binding remains in that spectrum; the full radiatively dressed response is used for scattering.

To identify the material response explicitly, let Q_N be a Hermitian nuclear charge-displacement coordinate that resolves internal motion, $\Delta_n = E_n - E_g$ an excitation gap above ground-state energy E_g , and $q_n = \langle 0|Q_N|n\rangle$ its transition charge matrix element. With reduced Planck constant $\hbar$, and the causal positive-infinitesimal prescription $i0^+$, one reciprocal channel with a unique ground state has the retarded response [1, Sec. 3.1; 3]

$$\chi^R(\omega) = 2 \sum_{n \neq 0} \frac{\Delta_n |q_n|^2}{\Delta_n^2 - \hbar^2 (\omega + i0^+)^2}. \quad (2)$$

The response uses the coupling $-VQ_N$ for probe voltage V and $e^{-i\omega t}$ time dependence. Continuum states enter through the corresponding spectral integral. The low-frequency storage expansion uses finite, physically regularized spectral sums on the responsive subspace.

Theorem on collective supporting power. Consider the matched material equilibria of [1], with the same internal mode patterns rescaled in size and frequency. Their current profiles, dissipative channels, temperatures and physical spectral cutoffs correspond. Let $R(\omega)$ be the Hermitian dissipative resistance matrix and $S_Q(\omega)$ the two-sided symmetrized charge spectral matrix. The trace, written Tr , sums diagonal matrix entries. With angular-frequency spectra normalized by the integration measure shown, the balanced power is

$$P = \int_{-\infty}^{\infty} \frac{d\omega}{2\pi} \omega^2 \text{Tr}[R(\omega)S_Q(\omega)], \quad P_{\text{in}} = P_{\text{out}} = P. \quad (3)$$

The integral adds exchange power across the internal modes and frequencies. Squared frequency converts charge fluctuations into current fluctuations; resistance converts those currents into outward power. In the equilibrium response account, incoming fluctuation power balances outward dissipation, with zero net exported power [1, Sec. 2.4; 3]. The matched transformations give

$$R_f(f\omega) = R_0(\omega), \quad S_{Q,f}(f\omega) = f^{-1}S_{Q,0}(\omega), \quad P_f = f^2 P_0. \quad (4)$$

Proof. Substitute the two transformations into the integral. The frequency interval contributes one factor of f , the squared frequency contributes two, and the charge spectrum contributes f^{-1} . Their product is f^2 . The trace includes correlations between modes, so the proof is collective. These matched transformations describe corresponding equilibria in the OQG theory; a general change of illumination need not preserve them. The theorem relates the adjusted states; the coupled scattering calculation determines which spatial profile is realized.

For one weakly damped radiative mode in its ground state, let R_{rad} be its radiation resistance, L_N its inductance, and γ_{rad} its energy relaxation rate. Evaluate the radiation resistance at the mode frequency. To leading order in weak damping, its balanced ground-state exchange is [1, Sec. 2.4; 4]

$$\gamma_{rad} = \frac{R_{rad}}{L_N}, \quad P_{rad} \simeq \gamma_{rad} \frac{\hbar\omega}{2}. \quad (5)$$

Both the relaxation rate and the mode energy scale by f , making the power scale by f^2 . Damping here describes the material mode's outward exchange. The shared field carries its influence to other positions; the damping coefficient itself is not a radial energy sink. At the adjusted equilibrium, incoming and outgoing powers remain equal even when their common value is lower.

How does this change become mechanical work? The nuclear inductance and capacitance describe magnetic and electric storage. For coupled modes, let I and q be current and charge columns, L and C their storage matrices, $v_C = C^{-1}q$ the voltage column, U_{st} stored electrical energy, and P_{ports} power delivered through the ports to this reversible storage sector. Dissipative exchange is accounted for in Eq. (3). The microscopic work identity is [1, Sec. 5.3]

$$P_{ports} = \dot{U}_{st} + \frac{1}{2} \langle I^T \dot{L} I \rangle + \frac{1}{2} \langle v_C^T \dot{C} v_C \rangle. \quad (6)$$

Dots denote time derivatives, T denotes transpose, and quantum products are symmetrized. The final two terms give power transferred into material deformation as electric and magnetic storage adjust, even when the body's center is held fixed. In the OQG theory, the same nuclear response that changes supporting exchange therefore also supplies the internal work underlying the complete-body energy relation below.

The complete reference rest energy E_0 includes binding and confinement. The material-energy theorem in [1, Sec. 5.1] then converts the adjusted exchange into recoverable work. For a slowly varying static profile, with the source configuration fixed, the storage gradient gives the comparison-coordinate momentum rate at instantaneous rest, denoted F:

$$E_{rest} = E_0 f = E_0 \sqrt{P/P_0}, \quad \mathbf{F} = -E_0 \nabla f = -\frac{E_0}{2\sqrt{P/P_0}} \nabla(P/P_0). \quad (7)$$

The storage gradient gives comparison-coordinate momentum change toward lower stored energy. A uniform reduction changes its supported state; a reduction that deepens toward another body produces attraction. The work of lifting is $E_0(f_2 - f_1)$. Thus power, measured in watts, selects the equilibrium, while the change in stored energy, measured in joules, supplies mechanical work. The source-dependent supporting state extends through the shared field to other receivers. A spatially varying state gives a spatially varying material energy; this dispersion interaction generates geodesic motion, as the following derivation shows.

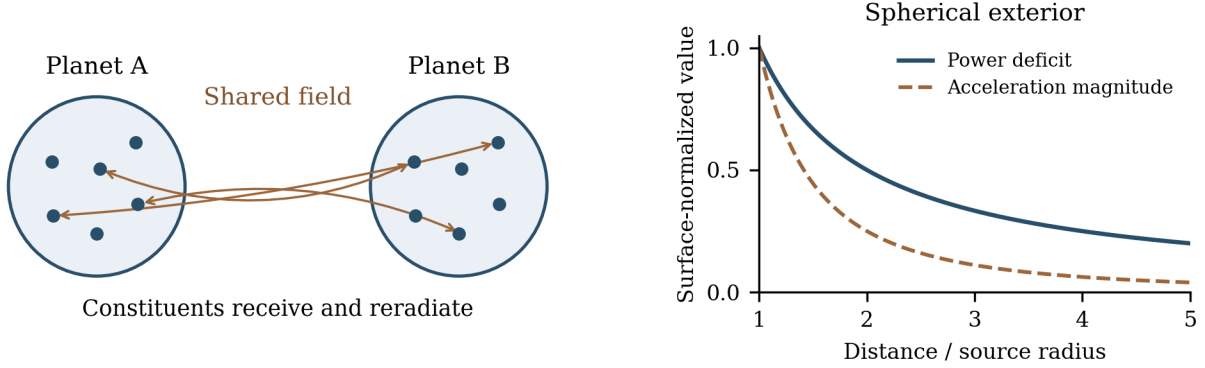


Figure 1. Left: constituent sources and receivers are coupled through the shared field; lines show mutual pathways, without representing phases or a computed intensity. Right: the calibrated spherical exterior in Eq. (16), with each curve normalized to its surface value. The deficit falls as inverse distance and the acceleration magnitude as inverse distance squared.

3 From dispersion interaction to geodesic motion

A dispersion force arises from correlated electromagnetic fluctuations; matter-wave dispersion relates a body's energy to its momentum. In OQG, scattering changes supporting exchange and material storage, and the resulting matter-wave dispersion governs propagation [1, Sec. 6].

For the propagation proof, neglect spin, tidal deformation and self-force corrections for a small freely falling body in prescribed smooth, static profiles $f(\mathbf{x}) > 0$ and $b(\mathbf{x}) > 0$. Let c_0 be the reference light speed, $m_0 = E_0/c_0^2$ the reference mass, H the energy in fixed comparison standards, $\mathbf{p}$ the canonical momentum, and t comparison time. A local stationary observer measures energy $E_{\text{loc}} = H/f$ and momentum $\mathbf{p}_{\text{loc}} = b\mathbf{p}$. In the OQG theory [1], the local Lorentz relation $E_{\text{loc}}^2 = E_0^2 + c_0^2 \mathbf{p}_{\text{loc}}^2$ gives

$$H = f\sqrt{E_0^2 + c_0^2 b^2 \mathbf{p}^2}, \quad \dot{\mathbf{x}} = \partial_{\mathbf{p}} H, \quad \dot{\mathbf{p}} = -\partial_{\mathbf{x}} H. \quad (8)$$

Dots denote derivatives with respect to t . In the eikonal approximation, a matter-wave packet follows these equations through a slowly varying environment. They give velocity and momentum change, including the moving body's ruler and momentum dependence. At instantaneous rest, the momentum equation reduces to Eq. (7). Differentiating the velocity equation at instantaneous rest gives $\frac{d^2x}{dt^2} = -c_0^2 f b^2 \nabla f$, reducing to $-c_0^2 \nabla f$ at leading weak-field order. Thus the coordinate acceleration also follows from the same Hamiltonian.

The same clocks and rulers define the material interval ds^2 . With moving-clock proper time τ and squared spatial coordinate displacement $d\mathbf{x}^2$,

$$ds^2 = -f^2 c_0^2 dt^2 + b^{-2} d\mathbf{x}^2 = -c_0^2 d\tau^2. \quad (9)$$

This metric records the material comparisons in Eq. (8). Define velocity $\mathbf{v} = \dot{\mathbf{x}}$, speed $v = |\mathbf{v}|$, Lagrangian $L = \mathbf{p} \cdot \mathbf{v} - H$, and action $S = \int L dt$. Substituting the first Hamilton equation into this Legendre transform gives

$$L = -E_0 \sqrt{f^2 - \frac{v^2}{b^2 c_0^2}}, \quad S = -m_0 c_0^2 \int d\tau. \quad (10)$$

For timelike motion, $v < f b c_0$, the square root equals $d\tau/dt$ from Eq. (9): the action is accumulated proper time times a constant. Let $x^0 = c_0 t$, with Greek indices labeling spacetime coordinates, and $\Gamma_{\alpha\beta}^\mu$ denote the connection coefficients of Eq. (9). Repeated indices are summed. Varying the action with fixed endpoints gives [1, Sec. 6.3; 5]

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma_{\alpha\beta}^\mu \frac{dx^\alpha}{d\tau} \frac{dx^\beta}{d\tau} = 0. \quad (11)$$

This is the geodesic equation. Coordinate acceleration and the connection term combine to give zero proper four-acceleration. The material Hamiltonian and clock-and-ruler metric therefore generate the same trajectory for the specified material profiles in the OQG theory.

An accelerometer measures the load between its proof mass and casing. Both fall freely together, so it reads zero; holding the casing at a fixed height produces a support load. This is the meaning of “gravity is not a force” in ideal free fall. Comparison-coordinate momentum can still change. OQG identifies scattering as the origin of the material profile; the dispersion interaction and geodesic description count its effect once.

The profiles here are independent of canonical momentum. Any additional motion-induced change of supporting equilibrium must enter the response and Hamiltonian consistently. The two-body example uses the leading conservative weak-field limit of this correspondence, rather than an exact moving-binary solution.

4 Relative motion in the shared field

Each body's response samples the field along its motion. Use one local inertial frame for the frequency transformation. In that frame, let ω and $\mathbf{k}$ be a field component's angular frequency and wavevector, $\mathbf{v}_j$ the velocity of body j , and c_0 the local light speed. The encountered frequency is [6]

$$\omega_j = \gamma_j(\omega - \mathbf{k} \cdot \mathbf{v}_j), \quad \gamma_j = \frac{1}{\sqrt{1 - v_j^2/c_0^2}}. \quad (12)$$

The dot product selects velocity along the propagation direction. Different directions shift differently. Field amplitudes, polarization and correlations accompany the frequency transformation. Scattering is evaluated in the body's instantaneous rest frame, then propagated to the next receiver.

For a freely propagating component in a locally uniform region, let $\mathbf{n}$ point from the source at emission to the receiver at reception. Subscripts s and r identify those events. The ratio below compares the emission and reception rest-frame frequencies in the flat-propagation limit; a varying material profile must also be included when extending it beyond that limit. The same phase gives

$$\frac{\omega_r}{\omega_s} = \frac{\gamma_r(1 - \mathbf{n} \cdot \mathbf{v}_r/c_0)}{\gamma_s(1 - \mathbf{n} \cdot \mathbf{v}_s/c_0)}. \quad (13)$$

Both motions belong to the same exchange. The emission and reception positions determine $\mathbf{n}$. The transformed spectrum enters the nuclear response and charge correlations before Eq. (3) is evaluated. Near fields and repeated scattering remain in the complete response.

The equal-mass circular example has a useful symmetry. In the leading flat-propagation approximation, write each center's velocity as $\mathbf{v}_j = \boldsymbol{\Omega} \times \mathbf{x}_j$, where $\boldsymbol{\Omega}$ is the common orbital angular velocity. The retarded ray joins $\mathbf{x}_s$ to $\mathbf{x}_r$, so $\mathbf{n} \cdot (\mathbf{v}_r - \mathbf{v}_s) = \mathbf{n} \cdot [\boldsymbol{\Omega} \times (\mathbf{x}_r - \mathbf{x}_s)] = 0$. Equal orbital radii also give equal speeds and equal Lorentz factors. Equation (13) therefore gives $\omega_r/\omega_s = 1$ for direct exchange between the centers in this idealized geometry.

The cancellation is a result of the two motions together. Each body still samples a direction-dependent ambient spectrum, and scattering still alters its supported state. Rotational symmetry permits a time-independent scalar exchange along each circular trajectory. A full moving-response calculation determines its value and any dissipative correction. The orbital demonstration below retains the calibrated conservative leading interaction from [1]; it does not infer absence of drag from the frequency cancellation alone.

Clock comparison is a further use of the resulting material state. Let t be fixed comparison time, τ a moving clock's proper time, and v its speed in the static comparison coordinates. The material interval in Eq. (9) gives

$$v_{\text{loc}} = \frac{v}{fb}, \quad \gamma_{\text{loc}} = \frac{1}{\sqrt{1 - v_{\text{loc}}^2/c_0^2}}, \quad \frac{d\tau}{dt} = \frac{f}{\gamma_{\text{loc}}}. \quad (14)$$

The factor f describes the material energy and clock scale, while $1/\gamma_{\text{loc}}$ describes motion through those local standards. Keeping b explicit preserves the independent ruler response. This clock comparison is applied after specifying the supported state.

5 Two planets in a circular orbit

Take two equal spherical planets of reference mass M , separated by center-to-center distance R , with sizes small compared with R . Neglect spins, tides and radiative orbital losses at this order. Their center of mass rests in the chosen isotropic ambient background. Each planet scatters the shared field, and each receives the field modified by its companion. Figure 2 shows their common circular orbit and the directions of coordinate momentum change and velocity.

Shared ambient field and mutually scattered contributions

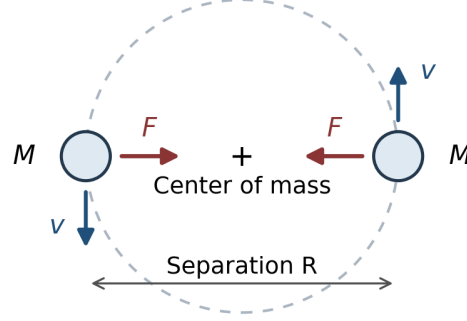


Figure 2. Equal masses orbit at radius $R/2$. The red arrows labeled F show inward comparison-coordinate momentum change, and the blue arrows show tangential velocity. These are freely falling trajectories; the red arrows do not represent an accelerometer load. The shared field includes the ambient and scattered contributions; the diagram represents geometry, not a computed field-intensity map.

For identical dipoles in a quasimonochromatic isotropic random field, tuning to an absorption Fröhlich resonance gives an attractive inverse-square interaction in the absorption-dominated, weak multiple-scattering regime [2]. OQG applies a calibrated inverse-distance interaction to complete material bodies [1]. Denote its positive pair coefficient by K . The interaction energy and outward-positive radial force are

$$U(R) = -\frac{K}{R}, \quad F_R = -\frac{dU}{dR} = -\frac{K}{R^2}, \quad K = GM^2. \quad (15)$$

Here G is the measured gravitational coupling. Matching K to GM^2 is the existing gravitational calibration; the orbital calculation uses that input. That illuminated-dipole result supplies an electromagnetic example, while a complete nuclear scattering calculation is needed to determine the macroscopic coefficient independently. The mutual energy U belongs to the pair and is counted once in the complete body–field energy. The two fixed-source receiver comparisons below are not added as independent copies of that pair energy.

The planets can now be resolved into their contributing material. In the OQG theory, the calibrated weak additive branch uses a mass-proportional inverse-distance interaction [1, Sec. 7.2]. For a test receiver in a fixed source environment, let $\rho(x')$ be the source mass density, x' a source position, x the receiver position, and m_0 its reference mass. Define the fractional supporting-power deficit $\delta_p = 1 - P/P_0$. Integrating over the source body gives

$$U(x) = -Gm_0 \int \frac{\rho(x')}{|x-x'|} d^3x', \quad \delta_p(x) \simeq \frac{2G}{c_0^2} \int \frac{\rho(x')}{|x-x'|} d^3x'. \quad (16)$$

For a spherical source, the shell integral outside the body reduces to total mass divided by distance from its center. All constituent contributions to this mass-proportional kernel are included; spherical symmetry permits their exterior effect to be represented by one mass. Thus each planet produces a radial deficit in the support available to a receiver. This is a profile of balanced material exchange, not the intensity of an outward radiation beam. Figure 1 distinguishes the constituent exchange from this macroscopic profile.

For either planet treated as receiver with its companion fixed, Eq. (7) represents this leading interaction through the companion-induced profile. The reference retains the receiver's own internal preparation and removes the companion's contribution. At leading weak-field order,

$$f(R) \simeq 1 - \frac{GM}{Rc_0^2}, \quad \frac{P(R)}{P_0} \simeq 1 - \frac{2GM}{Rc_0^2}, \quad -Mc_0^2 \frac{df}{dR} \simeq -\frac{GM^2}{R^2}. \quad (17)$$

Supporting power is lower closer to the companion and increases outward. Its gradient therefore supplies the inward coordinate momentum change in the weak-field limit of Eq. (8). Both planets have the same power ratio at their centers, but each occupies a point in a spatially varying profile. Equal local values do not remove those gradients. Equation (17) is the exterior profile of the distributed source in Eq. (16). Its deficit falls as inverse distance, while its gradient gives the inverse-square acceleration.

Each orbit has radius $R/2$. At leading order, geodesic motion gives the inward coordinate acceleration represented by the Newtonian mutual force on mass M . If v is each planet's orbital speed and T the period,

$$\frac{GM^2}{R^2} = \frac{Mv^2}{R/2}, \quad v^2 = \frac{GM}{2R}, \quad T = 2\pi \sqrt{\frac{R^3}{2GM}}. \quad (18)$$

The orbit is the leading weak-field geodesic result obtained from the calibrated supporting-power profile. For two nominal Earth-mass bodies, use the IAU nominal terrestrial mass parameter [7], $GM = 3.986004 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$, $R = 100,000 \text{ km}$, and the reference light speed $299,792,458 \text{ m s}^{-1}$. Each travels at 1.412 km s^{-1} and completes an orbit in 61.8 hours. The inward acceleration is 0.03986 m s^{-2} . The companion-induced power deficit in Eq. (17) is 8.87×10^{-11} , approximately 89 parts per trillion.

In the center-of-mass frame, the coordinate momentum rate and velocity are perpendicular. Consequently $\mathbf{F} \cdot \mathbf{v} = 0$: the interaction redirects the velocity without changing its magnitude. The separation, supported state and orbital energy remain constant in this conservative approximation. Supporting power continues to flow into and out of internal modes at equal rates. The centers follow geodesic motion at this order, with zero proper acceleration despite nonzero inward coordinate acceleration. Sustained orbital motion therefore requires no continual drain of orbital energy.

6 Conclusions

OQG locates the physical cause of gravity in the exchange between matter and its electromagnetic environment. The atomic and nuclear constituents throughout each body scatter the field that the constituents of the other body receive. Retarded propagation carries their mutual influence, and the collective response produces the radial supporting-power profile. Interference changes the supporting exchange, and the corresponding nuclear response changes material storage, clock frequencies and dimensions. Where that supported state varies with position, the material Hamiltonian governs free-fall motion.

The collective power theorem makes the connection quantitative: the balanced exchange scales as f^2 , complete rest energy scales as f , and the gradient of that energy gives recoverable gravitational work. Relative motion enters through the arriving spectrum and the receiving response. The circular example shows that source and receiver shifts must be treated together and that steady exchange can accompany continuous orbital acceleration.

On the calibrated conservative branch, two equal planets follow the expected orbit about their center of mass. The same supporting-power profile supplies their material-energy difference and geodesic motion. This is the OQG account demonstrated here: scattering establishes the electromagnetic conditions of support, matter adjusts its energy to those conditions, and its energy–momentum relation directs freely falling matter along geodesics with zero proper acceleration. Geometry records the clock, ruler and trajectory comparisons generated by this material response. The microscopic cause proposed by OQG remains the coupled matter–field response; the orbital result applies that account with the gravitational strength fixed by measurement.

Statements and Declarations

Funding. This work was self-funded by the author. No funds, grants, or other external support were received during the preparation of this manuscript.

Conflict of Interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

Author contributions. Todd J. Desiato conceived the OQG program and the material-scaling interpretation, directed the theoretical development, reviewed the calculations and literature, and prepared the manuscript.

Data availability. This theoretical study generated no new experimental or observational datasets. The analytical derivations and the parameters and results of the two-planet orbital example are contained in the article.

Code availability. The analytical identities and the two-planet orbital example can be reproduced directly from the equations and numerical parameters in the article without proprietary software.

Ethics approval and consent to participate. Not applicable. This study involved no human participants, human data, animals, or biological material.

Consent for publication. Not applicable.

Use of generative artificial intelligence. The author used OpenAI ChatGPT and Codex for literature discovery, mathematical cross-checking, numerical evaluation, organization, drafting, and editing. The author is responsible for reviewing the scientific arguments, equations, references, and final text and for the content of the manuscript.

Supplementary information. The analytical derivations and supporting calculations are included in the article. No separate supplementary files accompany this article.

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