# Gravitational Polarity Symmetry: Gravity, the Speed of Light, and Quantum Geometry from a Chiral Vacuum

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### Abstract

The vacuum energy problem is one of the central unresolved tensions between quantum theory and gravitation. Quantum field theory predicts a vacuum energy density near $10^{113}$ J/m$^3$, which in General Relativity would generate severe spacetime curvature, yet observation finds space remarkably flat.

This article argues that the discrepancy traces to a centuries-old conceptual error: the nature of energy itself has been misclassified.

Energy has been treated as a universal scalar currency, a single real-valued quantity. Yet close examination of the quantum substrate reveals that energy possesses an irreducible two-component structure. Maxwell showed this through light's two orthogonal polarizations. Dirac demanded it with his positive and negative energy solutions.

Consider the foundational statement: energy curves spacetime. If energy is complex, how does such curvature manifest? Equally along two internal axes. Within this framework, the vacuum, perfectly balanced, yields no net observable curvature—resolving the catastrophe.

But what of the exquisite curvature GR predicts so accurately around planets and stars?

Precisely there. In GR, energy curves spacetime. What produces this curvature? Planets and stars. The imbalance of the vacuum's perfect symmetry. Spacetime curvature emerges only where the two components of energy depart from equilibrium.

What follows develops this construction and its implications for quantum gravity—one where the vacuum sets the speed of light through its total amplitude, and curvature arises solely from asymmetry.

***Keywords*** Gravitational Polarity Symmetry · Povazanec gravity equation · Povazanec constant · Chiral Dipole Field · Vacuum Energy · Photon · Maxwell · Dirac · Spacetime

## Convention Note

Throughout this paper, “left-chiral” and “right-chiral” refer to circular polarisation of light — opposite to the $\gamma^5$ convention in particle physics, where the names are swapped.

No physical content depends on the choice.

## 1 Introduction

This article offers the reader a choice. One may continue the effort to resolve the vacuum catastrophe by seeking mechanisms to compensate an enormous vacuum energy. Or one may entertain an alternative: that vacuum energy is intrinsically twofold. The two components exert equal stress upon the inner curvature of spacetime along the real and imaginary axes, thereby maintaining flat spacetime—as observed—while reducing the speed of light from an unbounded value to a finite constant—also as observed. When this balance is disrupted, spacetime curves.

Domains where the difference $\rho_L - \rho_R > 0$ correspond to matter-dominated regions, characterized by positive energy density, exemplified by the Sun–Earth–Moon system. Domains where $\rho_L - \rho_R < 0$ correspond to antimatter-dominated regions, characterized by negative energy density.

The twofold structure is not a hypothesis introduced here — it has been present in the equations all along. In Maxwell’s electrodynamics, light polarization decomposes into horizontal and vertical components—two independent oscillations that together describe the full state yet remain distinct. In Dirac’s equation, the four-component spinor separates into positive and negative energy halves, matter and antimatter. In quantum field theory, this becomes explicit: the Dirac field splits into $\psi$ and $\overline{\psi}$, particle and antiparticle, two conjugate fields rotating with opposite phase in the complex plane.

The discovery that the vacuum is not empty came in stages. First, Planck found he needed a residual energy at absolute zero to make his blackbody formula work. Then Heisenberg showed that a confined field cannot be perfectly still. By the time quantum field theory matured, the picture was clear: every mode of every field hums with a minimum energy, a zero-point fluctuation that cannot be switched off. Summing these contributions across all possible modes gives a number. A huge number. So huge that if it coupled to gravity as ordinary energy does, the universe would have curled up long ago. Yet spacetime is flat. The calculation is correct. The conclusion is impossible. This is the vacuum catastrophe, and this article proposes a solution.

The solution begins with a simple observation. The traditional vacuum energy calculation assumes that all zero-point contributions add together into a single sum that gravitates. But if vacuum energy is twofold—paired components that stress spacetime in opposite senses—then the quantity that curves spacetime is not the total. It is the imbalance. The enormous number obtained from summing all modes is real. It simply does not gravitate. What remains to curve spacetime is only the local difference between the two components, a residual that is small, variable, and matches what we already measure as matter, radiation, and dark energy. The catastrophe vanishes not by canceling the energy, but by recognizing that it was never a single entry in the ledger to begin with.

If this picture is correct, it does not introduce new predictions so much as it explains what is already observed. The flatness of spacetime follows directly from the equal stress of the two components. The Casimir effect, long understood as a manifestation of vacuum fluctuations, remains real—the energy is there, and it is responsible for slowing the speed of information. In the Casimir regime, where vacuum energy is reduced, the speed of light increases relative to its usual value.

The approach does not merely patch the catastrophe — it changes what questions can be asked. With the vacuum catastrophe resolved, quantum field theory and general relativity may finally meet without contradiction. More fundamentally, it offers what GR has never been able to provide: an account of what spacetime is made of. In this framework, spacetime is not the stage on which physics happens — it is the collective behavior of a balanced chiral vacuum. When you know what spacetime is made of, you can ask what happens when it is pushed to extremes. The black hole interior — territory formally forbidden since Schwarzschild, where GR's equations fall silent at a singularity — becomes a landscape that can be explored: in this framework, the singularity retreats to infinite geodesic distance, and the inside of a black hole is no longer the place where physics ends. It is the place where it deepens.

# 2 One Quarter of the Deck

In the early twentieth century, Newton's laws served as the calibrated floor beneath physics. Einstein, probing the constancy of light's speed, produced Special Relativity. Probing the equivalence of gravity and acceleration, he produced General Relativity. Spacetime became a dynamical fabric, curved by the presence of energy and mass.

Yet the theory was constructed with the conceptual materials of its era. Energy was treated as a real, positive scalar. Vacuum energy was unknown. Antimatter was unknown. Einstein worked with one quarter of the deck.

The full deck:

- $L_0$ — Vacuum matter energy
- $R_0$ — Vacuum antimatter energy
- $\Delta L$ — Excess matter energy
- $\Delta R$ — Excess antimatter energy

Einstein had only $\Delta L$. He was missing $L_0$, $R_0$, and $\Delta R$. Three quadrants of reality were invisible at GR's birth.

Dirac's equation later demanded two solutions — electron and positron — forcing antimatter into existence. Feynman reframed the positron as an electron moving backward in time. The two-component nature of energy was now mathematically unavoidable. Its gravitational implications were simply set aside. Antimatter was assumed to "fall down." No one tested it.

Einstein, confronting his equations' refusal to yield a static cosmos, introduced the cosmological constant as a balancing term. Vacuum energy was not considered its source. Had it been, the predicted curvature would have been catastrophic. Since space appeared flat, vacuum energy was implicitly taken as zero.

Quantum field theory later filled that vacuum with $10^{113}$ J/m$^3$. The number is not wrong. The assumption that it must curve spacetime is wrong. Energy was never a scalar. The vacuum, in perfect internal balance, was never going to curve anything.

# 3 Two Energy Components Assignment

General relativity couples gravity to the stress-energy tensor $T_{\mu\nu}$, which sums all energy regardless of chirality. This paper argues that this is the wrong channel assignment.

The Dirac equation divides energy into two chiral sectors: left ($\rho_L$) and right ($\rho_R$). From these, two independent combinations exist — and they do two different things:

| **Combination** | **What it does in this paper** | **GR's treatment** |
|---|---|---|
| $\rho_L + \rho_R$ | Sets the propagation speed | Assigned to curvature → catastrophe |
| $\rho_L - \rho_R$ | Produces curvature | Not distinguished from $\rho_L + \rho_R$ |

These two combinations are not arbitrary. From any complex field $D = \psi_L + i\psi_R$, the $U(1)$ symmetry $D \to e^{i\alpha}D$ produces exactly two independent invariant bilinears: $|D|^2 = \psi_L^2 + \psi_R^2$ (the Noether charge density — the conserved quantity of the symmetry) and $C = \psi_L \partial_t \psi_R - \psi_R \partial_t \psi_L$ (the Noether current). These are the only two, and they are the sum and the difference of the chiral amplitudes. The decomposition is complete not because we chose it — it is what $U(1)$ symmetry gives.

The vacuum has $\rho_L = \rho_R$ (chiral symmetry). Therefore $\rho_L + \rho_R \sim 10^{113}$ J/m³ — enormous — but $\rho_L - \rho_R = 0$. GR routes the full $10^{113}$ J/m³ into curvature and predicts a universe collapsed into a point. This framework routes it into the propagation speed and predicts flat spacetime with $v = c$. The curvature channel sees zero. This is the vacuum catastrophe resolved — not by cancellation, but by **correct routing**.

For matter, GR's unsigned treatment gives the same answer as the signed treatment. But the reason is more precise: GR's stress-energy tensor measures energy *above* the vacuum — it sees the perturbation $(L_0 + \delta L) - (R_0 + 0)$, where $L_0 = R_0$ is the vacuum baseline. The vacuum parts cancel, leaving $\delta L$ — which is exactly $\rho_L - \rho_R$. GR is, without knowing it, a theory of $L_0 + \delta L - R_0 - 0 = \delta L$. It has been doing the $L - R$ subtraction all along, because it only encounters left-chiral perturbations ($\delta R = 0$ for matter) on a balanced vacuum. The distinction becomes visible only when $\delta R \neq 0$ — in regions containing antimatter.

The framework makes three claims:

1. The speed of light is not a fundamental constant — it is the propagation speed of the vacuum medium, set by $\rho_L + \rho_R$ through the Povazanec gravity equation $v = \mathcal{P}_v/\sqrt{\rho_L + \rho_R}$.
2. Gravity curvature is sourced by the chiral difference $\rho_L - \rho_R$, not the total energy. Matter and antimatter source gravity with opposite signs.
3. The geometry underlying these two channels is a two-radius torus $T^2$: the large radius carries $v$, the small radius carries the dilation field $\kappa$.

# 4 Dirac's Negative Energy Solutions

Dirac's relativistic wave equation for a particle of mass $m$:

$$(i\hbar\gamma^\mu \partial_\mu - mc)\Psi = 0 \tag{1}$$

where $\gamma^\mu$ are Dirac matrices, $\partial_\mu$ is the spacetime derivative, $\Psi$ is the spinor field, $m$ is mass, $c$ is the speed of light, and $\hbar$ is the reduced Planck constant.

yields four solutions at each momentum: two with eigenvalue $+E$, two with $-E$, where $E = \sqrt{(pc)^2 + (mc^2)^2}$. The standard reading interprets $-E$ as negative energy — requiring the Dirac Sea or normal ordering. We read it differently: the sign is chirality.

## 4.1 The Massless Case

For $m = 0$, the equation decouples into two independent Weyl equations:

$$\begin{aligned} i\hbar\partial_t\psi_L &= -i\hbar c(\sigma\cdot\nabla)\psi_L \\ i\hbar\partial_t\psi_R &= +i\hbar c(\sigma\cdot\nabla)\psi_R \end{aligned} \tag{2}$$

The sign flip between left and right is the origin of $\pm E$. For a photon propagating in $\hat{z}$, the solutions are:

$$\begin{aligned} &\text{Left-Circular:} \quad && \phi_L = Ae^{i(kz-\omega t)} \quad && (+E \text{ sector}) \\ &\text{Right-Circular:} \quad && \phi_R = Ae^{-i(kz-\omega t)} \quad && (-E \text{ sector}) \end{aligned} \tag{3}$$

Both carry positive physical energy $E = \hbar\omega > 0$. The sign does not label energy — it labels the direction of rotation in the complex plane. This is directly observable as the helicity of circularly polarised light.

## 4.2 The Massive Case

The same structure persists when $m > 0$. The mass term couples the two Weyl sectors but does not change the rotation direction:

| **Phase rotation** | **Complex plane** | **Helicity** | **Massless ($m = 0$)** | **Massive ($m > 0$)** |
|---|---|---|---|---|
| $e^{-i\omega t}$ | Counter-clockwise | $h = +1$ | Left-circular photon | Electron (matter) |
| $e^{+i\omega t}$ | Clockwise | $h = -1$ | Right-circular photon | Positron (antimatter) |

The electron rotates as $e^{-iEt/\hbar}$ — the same direction as the left-circular photon. The positron rotates as $e^{+iEt/\hbar}$ — the same as the right-circular photon. Mass couples the branches; it does not move a particle from one to the other. The branch identity is fixed by the Dirac equation itself.

## 4.3 The $\pi/2$ Structure

At rest ($\boldsymbol{p} = 0$), the Dirac Hamiltonian reduces to $H = \beta mc^2$, where $\beta$ swaps $\psi_L \leftrightarrow \psi_R$. Its eigenvectors, mapped through $D = \psi_L + i\psi_R$, give:

$$\begin{aligned} +E: &\quad D = \chi(1+i) = \chi\sqrt{2}\,e^{i\pi/4} \qquad (\text{at} + 45^\circ\ ) \\ -E: &\quad D = \chi(1-i) = \chi\sqrt{2}\,e^{-i\pi/4} \quad (\text{at} - 45^\circ\ ) \end{aligned} \tag{4}$$

The two Dirac branches are separated by $\pi/2$ in the complex plane — not $\pi$ on the real line. The historical reading projected a two-dimensional complex rotation onto a one-dimensional real axis. The minus sign was never about energy. It was always about the geometry of the complex plane.

Dirac's equation divides the universe into two chiral sectors: left (matter) and right (antimatter). We take this division seriously — including its gravitational consequences.

# 5 The Chiral Dipole Field

## 5.1 The Scalar Field

A single complex scalar field at each point of spacetime:

$$D(x^\mu) = \psi_L(x^\mu) + i\psi_R(x^\mu) \tag{5}$$

where $\psi_L$ and $\psi_R$ are real-valued chiral amplitudes. The $i$ is physically mandated by the $\pi/2$ phase relationship between the electric and magnetic fields of circularly polarised light (Section 4). The dynamics follow from the Lagrangian:

$$\mathcal{L} = \frac{1}{2}\,|\partial_\mu\psi_L|^2 + \frac{1}{2}\,|\partial_\mu\psi_R|^2 - \frac{1}{2}k\,|D|^2 \tag{6}$$

where $k$ is the vacuum stiffness — making $D$ a two-dimensional harmonic oscillator at each spacetime point.

This scalar construction captures the essential chiral structure — two components at $\pi/2$, counter-rotating states, signed gravitational source — in its simplest form. It is a stepping stone: it demonstrates that light — as energy — can propagate through a complex-valued structure and reproduce Maxwell's electromagnetism exactly (Section 4). The gravitational model requires the toroidal geometry developed in Section 12.

### 5.1.1 The Stiffness–Speed Relation

The Lagrangian contains a single free scale: the vacuum stiffness $k$. It is not independent of the speed of light. Each vacuum oscillator hums at frequency $\omega_0 = \sqrt{k}$; the zero-point energies of all modes sum to $\rho_{\text{vac}}$; and $\rho_{\text{vac}}$ sets the propagation speed through the Povazanec equation (Equation 13). The direction of the chain is counterintuitive: a *stiffer* vacuum — higher $k$, higher $\omega_0$, more zero-point energy — produces a *slower* speed of light. This is opposite to classical mechanics, where stiffer means faster, but it follows directly from the vacuum being a *damping* medium: more energy in the medium means more resistance to propagation, not more coupling between neighbours.

The consequence is that the model has one free scale, not two. Given $k$ (or equivalently $\rho_{\text{vac}}$), the speed of light is determined. Given $c$ and the Planck constants, $k$ is determined. The Lagrangian parameter and the universal speed constant are the same quantity viewed from two directions.

## 5.2 Physical Quantities

The field $D$ encodes three distinct physical quantities:

| **Quantity** | **Expression** | **Physical Meaning** |
|---|---|---|
| Energy Density | $\rho_E \propto \|D\|^2 = \psi_L^2 + \psi_R^2$ | Total field intensity — always positive |
| Chiral Current | $C = \psi_L \partial_t \psi_R - \psi_R \partial_t \psi_L$ | Angular momentum of $D$ in the complex plane — signed |
| Gravitational Source | $\rho_{\text{grav}} = \kappa_0 C$ | Spacetime curvature — signed by chirality |

The chiral current $C$ is the conserved Noether charge of the $U(1)$ symmetry $D \to e^{i\alpha}D$. It changes sign under complex conjugation $D \to D^*$. This is the origin of signed gravity: the symmetry that relates matter to antimatter is the same symmetry that reverses the gravitational source. (And it matches the Feynman's backward in time transformation.)

## 5.3 Vacuum and States

The vacuum is the ground state $\langle D \rangle = 0$: both chiralities fluctuate symmetrically, with $\langle C \rangle = 0$ and therefore $\langle \rho_{\text{grav}} \rangle = 0$. The vacuum does not gravitate. Zero-point fluctuations are real [1], but the gravitational contributions of left and right modes cancel by symmetry.

The excitations of $D$ are:

| **State** | $\boldsymbol{D}$ | **Chiral Current** $\boldsymbol{C}$ | **Gravitational Source** |
|---|---|---|---|
| Vacuum | $\langle D \rangle = 0$ | 0 | Zero — flat spacetime |
| Left-Circular Photon | $Ae^{\{i(kz-\omega t)\}}$ | $-A^2\omega$ | Attractive |
| Right-Circular Photon | $Ae^{\{-i(kz-\omega t)\}}$ | $+A^2\omega$ | Repulsive |

The two photon states are related by $D_{\text{right}} = D^*_{\text{left}}$ — complex conjugation reverses the rotation and flips the gravitational sign.

For a single photon of frequency $\omega$ in volume $V_{\text{box}}$:

$$\frac{1}{2}kA^2V_{\text{box}} = \hbar\omega \qquad \Rightarrow \qquad A^2 = \frac{2\hbar\omega}{kV_{\text{box}}} \tag{7}$$

The amplitude scales as $\sqrt{\omega}$ — this determines the gravitational source strength for circularly polarised light.

# 6 Connection to Maxwell

The chiral dipole field is not a new electromagnetic theory — it is Maxwell's equations rewritten in a language that exposes the chiral structure.

The Riemann–Silberstein (RS) complex 3-vector:

$$\boldsymbol{F} = \boldsymbol{E} + ic\boldsymbol{B} \tag{8}$$

casts Maxwell's equations as:

$$\partial_t \boldsymbol{F} = -ic(\nabla \times \boldsymbol{F}), \qquad \nabla \cdot \boldsymbol{F} = 0 \tag{9}$$

For a wave propagating in $\hat{z}$, the circular polarisation components $F_\pm = F_x \pm iF_y$ decouple:

$$\begin{aligned} \partial_t F_+ &= -ic\partial_z F_+ \qquad \text{(Left-Circular)} \\ \partial_t F_- &= +ic\partial_z F_- \qquad \text{(Right-Circular)} \end{aligned} \tag{10}$$

with solutions $F_+ = Ae^{i(kz-\omega t)}$ and $F_- = Ae^{-i(kz-\omega t)}$. Each circular polarisation mode is a complex scalar — identical in form to $D$:

| **Maxwell (RS)** | **Chiral Dipole** | **Photon** |
|---|---|---|
| $F_+ = Ae^{i(kz-\omega t)}$ | $D = Ae^{i(kz-\omega t)}$ | Left-Circular |
| $F_- = Ae^{-i(kz-\omega t)}$ | $D^* = Ae^{-i(kz-\omega t)}$ | Right-Circular |

Same wave equation ($\Box D = 0$), same dispersion ($\omega = |k|c$), same two-state structure. The $\pi/2$ phase between $\boldsymbol{E}$ and $\boldsymbol{B}$ in circularly polarised light is precisely the $i$ in $D = \psi_L + i\psi_R$:

$$\psi_L = A\cos(kz - \omega t), \qquad \psi_R = A\sin(kz - \omega t) \tag{11}$$

The chiral current confirms the gravitational sign assignment:

$$C_{\text{left}} = -A^2\omega, \qquad C_{\text{right}} = +A^2\omega \tag{12}$$

The chiral split of electromagnetism into left and right circular modes is established physics. What we add is the gravitational consequence: the two modes source gravity with opposite signs.

| **Photon** | **Chiral current $C$** | **Gravitational source** |
|---|---|---|
| Left-circular ($e^{i(kz-\omega t)}$) | $-A^2\omega$ | Attractive ($\kappa < 1$) |
| Right-circular ($e^{-i(kz-\omega t)}$) | $+A^2\omega$ | Repulsive ($\kappa > 1$) |

It is the first and most immediate consequence of the chiral framework applied to the photon field. **One photon creates a valley; the other creates a hill.** Unpolarised light — an equal mixture of both — creates neither: $C_{\text{left}} + C_{\text{right}} = 0$, zero net gravitational source.

# 7 Two Components of Gravity

The total energy density at any point decomposes into left-chiral and right-chiral contributions: $\rho_L$ and $\rho_R$. From these, exactly two independent combinations can be formed:

| **Parameter** | **Symbol** | **Sourced by** | **Physical role** |
|---|---|---|---|
| Propagation speed | $v$ | $\rho_L + \rho_R$ (chiral sum) | Speed of light — set by total vacuum intensity |
| Dilation field | $\kappa$ | $\rho_L - \rho_R$ (chiral difference) | Curvature — gradients produce gravity |

There is no third combination. This decomposition is complete.

# 8 Vacuum Energy Sets the Speed of Light

We propose that the enormous vacuum energy density does not curve spacetime into a ball. It curves it uniformly — and a uniform curvature is indistinguishable from flat spacetime with a finite propagation speed. The vacuum energy becomes the *medium* through which signals travel.

The $1/\sqrt{\rho}$ scaling has a precise physical origin. Every wave in every elastic medium obeys $v = \sqrt{\text{stiffness / inertia}}$: transverse waves on a string travel at $v = \sqrt{T/\mu}$, sound through a gas at $v_s = \sqrt{\gamma P/\rho}$, phonons through a crystal at $v \approx a\sqrt{K/m}$. In each case two properties compete — the restoring force that drives propagation and the inertia that resists it.

The vacuum has both required properties. Its stiffness is $\mathcal{P}_v^2$ — encoded in the gradient term of the Lagrangian, the same constant that appears in the Povazanec equation (Equation 13). Its inertia is the zero-point energy density $\rho_{\text{vac}} \sim 10^{113}$ J/m³. Their ratio gives the propagation speed. The speed of light is not a law of nature. It is the wave speed of the vacuum medium.

Curiously, this inertial medium offers no resistance to uniform motion — it slows light, but exerts no drag on matter. Newton's first law may be a consequence of the vacuum's rigid consistency rather than a default absence of force.

This gives the speed of light an origin — the **Povazanec gravity equation**:

$$v = \frac{\mathcal{P}_v}{\sqrt{\rho_L + \rho_R}} \tag{13}$$

where $\mathcal{P}_v$ is the **Povazanec gravity constant**.

This is not purely theoretical. The Casimir effect [1] proves that vacuum energy is real and physically consequential: two uncharged conducting plates attract each other because the conducting boundary excludes long-wavelength vacuum modes between them, lowering the energy density relative to free space. When the vacuum energy density is reduced this way, the equation predicts $\upsilon > c$ between the plates — a result derived three decades earlier from full QED by Scharnhorst and Barton [2], [3]. A medium with less inertia propagates faster. The vacuum is no different.

The functional form $1/\sqrt{\rho}$ is not arbitrary — it is the universal scaling of wave propagation in any elastic medium, the same law that governs the speed of sound in a fluid and phonons in a lattice. In our dense vacuum, $\upsilon = c = 299\,792\,458$ m/s. Macroscopic energy densities are negligible compared to $\rho_{\text{vac}} \sim 10^{113}$ J/m³, so $\upsilon$ is effectively constant everywhere — which is why $c$ appears to be a universal constant. It is universal for us. A different vacuum density would give a different "speed of light."

Consider the limiting case. If the vacuum energy were zero — no fluctuations, no medium — the denominator vanishes: $\upsilon \to \infty$. Signals would propagate instantaneously. Finite $c$ is not a law unto itself — it is the result of slowing down an *infinite* propagation speed. The vacuum energy density of $10^{113}$ J/m³ is what it takes to bring infinity down to $3 \times 10^8$ m/s.

# 9 The Constant $\mathcal{P}_\upsilon$

The constant $\mathcal{P}_\upsilon$ in the Povazanec gravity equation $\upsilon = \mathcal{P}_\upsilon / \sqrt{\rho_L + \rho_R}$ — the Povazanec gravity constant — is the fundamental quantity of this framework. It is not $c$. The speed of light is *derived* from $\mathcal{P}_\upsilon$ and the vacuum energy density. $\mathcal{P}_\upsilon$ is the constant that encodes how energy density translates into propagation speed — the conversion factor between the intensity of the vacuum and the rate at which information can traverse it.

## 9.1 Deriving the vacuum energy density

The vacuum energy density is not a free parameter — it is determined by the three established constants of physics: $G$, $c$, and $\hbar$. The Planck energy density is:

$$\rho_P = \frac{c^7}{\hbar G^2} \tag{14}$$

Substituting measured values:

$$\rho_P = \frac{(2.998 \times 10^8)^7}{(1.055 \times 10^{-34})(6.674 \times 10^{-11})^2} \approx 4.6 \times 10^{113}\,\text{J/m}^3 \tag{15}$$

This is the natural scale for vacuum energy in any theory that contains gravity ($G$), quantum mechanics ($\hbar$), and relativity ($c$) [4], [5]. In this framework, $\rho_{\text{vac}}$ is fixed uniquely by $\rho_P = c^7/(\hbar G^2)$ — no free parameters enter.

## 9.2 The value of $\mathcal{P}_\upsilon$

The propagation equation:

$$\upsilon = \mathcal{P}_\upsilon / \sqrt{\rho} \tag{16}$$

gives:

$$\mathcal{P}_\upsilon = c\sqrt{\rho_{\text{vac}}} \tag{17}$$

Raising to the fifth power:

$$\mathcal{P}_v^5 = c^5 \cdot \rho_{\text{vac}}^{5/2} \tag{18}$$

Inserting $G/G = 1$ and recognising $c^5/G \equiv P_P$ (the Planck power):

$$\mathcal{P}_v^5 = G \cdot \underbrace{(c^5/G) \cdot \rho_{\text{vac}}^{5/2}}_{\equiv \mathcal{P}} \tag{19}$$

Taking the fifth root:

$$\mathcal{P}_v = (G \cdot \mathcal{P})^{1/5} \tag{20}$$

Dimensional analysis confirms:

$$[G \cdot \mathcal{P}] = \text{kg}^{5/2} \cdot \text{m}^{5/2} \cdot \text{s}^{-10} \qquad \rightarrow \qquad [\mathcal{P}_v] = \text{kg}^{1/2} \cdot \text{m}^{1/2} \cdot \text{s}^{-2} \tag{21}$$

In closed form, using $\rho_{\text{vac}} = \rho_P = c^7/(\hbar G^2)$:

$$\mathcal{P}_v = c \cdot \sqrt{\rho_P} = \frac{c^{9/2}}{\sqrt{\hbar} \cdot G} \tag{22}$$

Numerically:

$$\mathcal{P}_v \approx 2.04 \times 10^{65}\, \text{kg}^{1/2} \cdot \text{m}^{1/2} \cdot \text{s}^{-2} \tag{23}$$

and the self-consistency check:

$$v = \mathcal{P}_v / \sqrt{\rho_{\text{vac}}} = (2.04 \times 10^{65})/(6.81 \times 10^{56}) = 2.998 \times 10^8 \frac{m}{s} = c \tag{24}$$

The calculation looks circular: compute $\mathcal{P}_v$ from $c$ and $\rho_{\text{vac}}$, then recover $c$ — of course the number comes back. But of the three quantities in $v = \mathcal{P}_v/\sqrt{\rho}$, only $\mathcal{P}_v$ is a constant. The energy density $\rho$ is not fixed — the Casimir effect physically lowers it between conducting plates, and the equation then predicts a different, higher propagation speed (a result Scharnhorst and Barton derived independently from full QED three decades earlier [2], [3]). Nor is $\rho$ purely the vacuum: the denominator contains the *total* chiral sum $\rho_L + \rho_R$ at each point, including any matter or radiation present. Near a star, the local energy density is higher than the vacuum baseline, and the equation predicts a correspondingly slower local propagation speed — though the correction is of order $\rho_{\text{matter}}/\rho_{\text{vac}} \sim 10^{-56}$, completely invisible next to the $\kappa$-channel effects that dominate all observable gravity. The self-consistency check is not the content of the equation. The content is that when the vacuum changes, $c$ changes with it — and $\mathcal{P}_v$ does not. No one will ever need the Povazanec equation to calculate the speed of light, which is already measured to nine digits. Its value is in revealing that $c$ is not a law but a response — and that the true constant is the one that survives when the vacuum is altered.

The expression:

$$\mathcal{P}_v = c^{9/2} / \left(\sqrt{\hbar} \cdot G\right) \tag{25}$$

contains no vacuum energy density, no cutoff, and no adjustable parameter. It is built entirely from $c$, $\hbar$, and $G$ — the three constants that define the intersection of relativity, quantum mechanics, and gravity.

## 9.3 The $1/5$ signature

The fifth root in $\mathcal{P}_v = (G \cdot \mathcal{P})^{1/5}$ is not numerology — it is the dimensional signature of the toroidal geometry (Section 12). In Kaluza-Klein theory, the gravitational constant in $d$ dimensions relates to the four-dimensional constant through the volume of the compact space. For a single compact circle — the toroidal direction of the torus — the effective coupling picks up one extra dimension, and the extraction of a speed from $G$ and $\rho_{\text{vac}}$ requires exactly a fifth root. The $1/5$ is the torus speaking.

## 9.4 Interpretation

The units $\left[\mathrm{kg}^{1/2} \cdot \mathrm{m}^{1/2} \cdot \mathrm{s}^{-2}\right]$ can be rewritten as $\mathrm{m} \cdot \mathrm{s}^{-1} \cdot \left(\mathrm{J} \cdot \mathrm{m}^{-3}\right)^{1/2}$ — a speed per square root of energy density. This is physically natural: $\mathcal{P}_v$ converts the square root of the vacuum's energy content into a propagation speed.

The chain of logic runs one way:

$$\{G, c, \hbar\} \to \rho_P = \frac{c^7}{\hbar G^2} \to \mathcal{P}_v = c \cdot \sqrt{\rho_P} = \frac{c^{9/2}}{\sqrt{\hbar} \cdot G} \to \upsilon = \frac{\mathcal{P}_v}{\sqrt{\rho_{\mathrm{vac}}}} = c \tag{26}$$

The speed of light is last, not first. It is the *output* of three deeper quantities. This is not circular — the self-consistency ($\upsilon = c$) is a check, not an assumption.

## 9.5 The fundamental constants of gravity

In the conventional framework, two quantities are treated as fundamental: Newton's constant $G$ and the speed of light $c$. In this framework, $G$ remains fundamental — it governs the coupling between chiral energy difference and curvature. But $c$ is replaced by $\mathcal{P}_v$:

| Constant | Status | Role |
|---|---|---|
| $G$ | Fundamental | Couples chiral difference to curvature ($\nabla^2\kappa = 4\pi G/\upsilon^2(\rho_L - \rho_R)$) |
| $\mathcal{P}_v$ (Povazanec constant) | Fundamental | Couples chiral sum to propagation speed ($\upsilon = \mathcal{P}_v/\sqrt{\rho_L + \rho_R}$) |
| $c$ | Derived | $c = \mathcal{P}_v/\sqrt{\rho_{\mathrm{vac}}}$ — a property of our vacuum, not a law of nature |

The closed-form expression $\mathcal{P}_v = c^{9/2}/\left(\sqrt{\hbar} \cdot G\right)$ shows that $\mathcal{P}_v$ is not a new free parameter — it is determined by the same constants that determine all of quantum gravity. What is new is the *role*: $\mathcal{P}_v$ is the constant that converts vacuum energy density into propagation speed. The speed of light is its most visible consequence, but $\mathcal{P}_v$ is the deeper quantity.

The two fundamental constants $G$ and $\mathcal{P}_v$ govern the two independent gravitational parameters: $G$ controls how much the chiral *difference* curves spacetime, and $\mathcal{P}_v$ controls how the chiral *sum* sets the propagation speed. One constant for each degree of freedom. Nothing is left over.

$\upsilon$ is not a gravitational field in the GR sense — it has no gradients, it produces no forces. It is the *background* on which gravity operates. It is the answer to what the vacuum energy is doing: not curving spacetime, but defining the speed at which information travels through it.

## 9.6 The $\upsilon$ correction near matter

In the presence of matter, the local propagation speed receives a tiny correction. Near an electron ($\rho_L = \rho_L^{\mathrm{vac}} + \Delta\rho$, $\rho_R = \rho_R^{\mathrm{vac}}$), the total chiral density increases:

$$\upsilon_{\mathrm{local}} = \frac{\mathcal{P}_v}{\sqrt{\rho_{\mathrm{vac}} + \Delta\rho}} \approx c\left(1 - \frac{1}{2}\frac{\Delta\rho}{\rho_{\mathrm{vac}}}\right) \tag{27}$$

The correction is of order $\rho_{\mathrm{matter}}/\rho_{\mathrm{vac}} \sim 10^{-56}$ — completely undetectable with any foreseeable technology. But it is structurally present: matter does not *only* curve spacetime through $\kappa$ (the chiral difference). It also infinitesimally slows the local propagation speed through $\upsilon$ (the chiral sum). Both effects originate from the same source, through the two independent combinations.

Standard GR has no analogue of this correction — $c$ is postulated constant, so matter cannot affect it. In this framework, the constancy of $c$ is an approximation valid to $10^{-56}$, not an axiom.

## 9.7 The two layers of the equation

The $10^{-56}$ correction seems irrelevant to experiment. It is not irrelevant to understanding. The Povazanec equation contains two layers of physical content, and separating them reveals the deepest structural insight of the framework.

**Layer 1: the $\upsilon$ channel (chiral sum).** The equation says that the entire mass of the Sun perturbs $\upsilon$ by one part in $10^{56}$. A stellar-mass black hole does no better. Nothing in the observable universe — no object, no event, no concentration of energy — leaves a measurable imprint on $\upsilon$. The vacuum is *incomprehensibly stiff*: $\mathcal{P}_\upsilon^2 \approx 4 \times 10^{130}$ Pa is its bulk modulus, the highest rigidity permitted by dimensional analysis. This is not a failure of experimental reach. It is a statement about the substrate: the quantum vacuum absorbs all matter-energy perturbations without measurably yielding. The speed of light is constant to 56 decimal places not because a law says so, but because the medium is that rigid.

**Layer 2: the $\kappa$ channel (chiral difference).** All gravitational phenomena ever observed — falling apples, planetary orbits, gravitational lensing, Shapiro delay, gravitational redshift, LIGO waves — live in the $\kappa$ channel. When GR says "the speed of light varies near a mass," it is reporting a change in $c_{\text{eff}} = \upsilon \cdot \kappa$, where $\kappa < 1$ — the coordinate speed of light *decreases*. This is not $\upsilon$ changing — it is $\kappa$ changing. The propagation speed of the vacuum is untouched; the local dilation field rescales rulers and clocks. GR conflates these two mechanisms because it has only one gravitational channel. The Povazanec equation is the only theoretical framework that separates them.

**The distinction.** No other theory makes this separation. General relativity cannot — it has one channel ($T_{\mu\nu}$). String theory does not address it at this level. Quantum field theory on curved backgrounds takes $c$ as given. The Povazanec equation is, as far as we are aware, the only equation in physics that tells us simultaneously *why the speed of light is so stable* (the vacuum is stiff) and *what gravity actually is* (an imbalance, not a total). For measurement, the $\upsilon$ correction is beyond all foreseeable technology. For ontology — for understanding the architecture of reality — it is the difference between a universe where $c$ is an unexplained law and a universe where $c$ is the 56-digit-stable response of a medium to its own energy content.

## 9.8 The Scharnhorst effect: $\upsilon > c$ between Casimir plates

The $\upsilon$ correction near matter shows the equation responding to *increased* energy density. The Casimir effect provides the opposite case — *decreased* energy density — and here the equation makes a non-trivial, independently testable prediction.

Between two conducting plates separated by distance $d$, vacuum modes with wavelengths larger than $d$ are excluded. The energy density between the plates is lower than outside:

$$\rho_{\text{between}} = \rho_{\text{vac}} - |\Delta\rho|, \qquad |\Delta\rho| = \frac{\pi^2 \hbar c}{720\, d^4} \tag{28}$$

The propagation equation responds immediately:

$$\upsilon_{\text{between}} = \frac{\mathcal{P}_\upsilon}{\sqrt{\rho_{\text{vac}} - |\Delta\rho|}} \approx c\left(1 + \frac{1}{2}\frac{|\Delta\rho|}{\rho_{\text{vac}}}\right)) \tag{29}$$

Light travels *faster* between Casimir plates. Less vacuum energy means less medium, less resistance, higher propagation speed.

This prediction is not unique to the Chiral Dipole Field. In 1990, Scharnhorst and Barton independently derived the same result from standard QED [2], [3]: the phase velocity of light between Casimir plates exceeds $c$ by a factor of order $|\Delta\rho|\ /\rho_{\text{vac}}$. Their calculation uses the full machinery of vacuum polarisation in bounded geometries. Our framework reproduces it from one line.

The correction is spectacularly small — for $d = 1\mu$m plates, $|\Delta\rho| \sim 10^{-4}$ J/m$^3$, giving $\Delta v/c \sim 10^{-117}$. No foreseeable technology can measure this. But the structural content is significant:

1. **The equation is not circular here.** The Casimir cavity has a different vacuum energy density than free space, and the equation predicts a different speed of light. Input and output differ.
2. **The sign is correct.** Less density → faster propagation, matching both the QED calculation and the condensed-matter analogy.
3. **The functional form matches.** The QED result scales as $1/d^4$ — exactly the Casimir energy density scaling — confirming the $1/\sqrt{\rho}$ dependence.
4. **No new physics is invoked.** The Casimir energy is established, measured, and non-controversial. The propagation equation simply responds to it.

The Casimir cavity is a laboratory realisation of a "different vacuum" — a region where the vacuum energy density takes a value other than $\rho_{\text{vac}}$. The framework predicts that every such modification of the vacuum changes the local speed of light, and the Scharnhorst effect confirms this.

# 10 The Dilation Field $\kappa$

The dilation field $\kappa(x)$ is a dimensionless scalar encoding local spacetime curvature. The effective local propagation speed is:

$$c_{\text{eff}}(x) = v \cdot \kappa(x) \tag{30}$$

In flat spacetime (balanced vacuum), $\kappa = 1$ everywhere and $c_{\text{eff}} = v = c$. Near matter ($\kappa < 1$), $c_{\text{eff}} < c$ — light slows in a gravitational well. Gradients in $\kappa$ produce gravitational acceleration.

The **Principle of Local Invariance**: an observer made of matter whose internal dynamics scale with $\kappa$ cannot locally measure $\kappa$ itself — only gradients. Clocks, rulers, and all physical processes adjust with $\kappa$. This is the equivalence principle, stated in network language.

For a test particle in the weak-field limit ($\kappa = 1 + \delta\kappa$, $|\delta\kappa| \ll 1$):

$$\vec{a} = -v^2 \nabla(\delta\kappa) \tag{31}$$

Identifying $\delta\kappa = \Phi/v^2$ with the Newtonian potential $\Phi$ gives the field equation:

$$\nabla^2\kappa = \frac{4\pi G}{v^2}(\rho_L - \rho_R) \tag{32}$$

For a point mass $M$ of pure matter ($\rho_L = \rho_{\text{matter}}$, $\rho_R = 0$):

$$\kappa(r) = 1 - \frac{GM}{v^2 r} \tag{33}$$

This is the $g_{tt}$ component of the Schwarzschild metric in isotropic coordinates — the Newtonian gravitational potential dressed into a time-dilation field. It is the content of Newtonian gravity and of gravitational redshift. The full weak-field metric requires also $g_{rr}$, which encodes spatial curvature; whether the $\tau$-field's spatial gradients reproduce it is a question that requires the non-linear extension developed in Section 12, and is not settled in this paper.

The sourcing equation depends on the *difference* $\rho_L - \rho_R$. For the vacuum, this difference is zero. For matter, it is the matter density. For antimatter, it is negative. The sign is not a postulate — it is inherited from the Dirac equation's chiral structure (Section 2).

# 11 Lorentz Invariance and the Network

The identification of the vacuum as a substrate raises the historical objection: does it define a preferred frame?

It does not. The vacuum state $|0\rangle$ is Lorentz-invariant [6]. The fluctuations are not "stuff" moving through space — they are fluctuations *of* space. The Lagrangian $\mathcal{L} = \frac{1}{2}\,|\partial_\mu D|^2$ is a Lorentz scalar. The chiral current $C$ transforms as a pseudoscalar density. No experiment can detect the network's "rest" because it has none.

The framework is Lorentz-invariant in the same precise sense as QED: the vacuum is a medium that cannot be used to define absolute motion.

We further propose the ontological claim: the **dipole network constitutes spacetime** rather than living within it.

| **Conventional concept** | **Network meaning** |
|---|---|
| A point in space | A single chiral oscillator |
| Distance | Inter-oscillator phase separation — not measured against space, but constitutive of it |
| Time | Phase evolution parameter |
| Spacetime curvature | Gradient in $\kappa$ — variation in local handshake speed |
| Flat spacetime | $\kappa = 1$ everywhere — balanced vacuum |

If $\upsilon$ is a property of the network and $\kappa$ encodes local deformation, then spacetime geometry is derivative of the network, not the other way around.

## 11.1 How $\kappa$ Propagates

Place a mass (left-chiral excess) at a point. It pinches the local torus: $r < r_0$, $\kappa < 1$. But the vacuum is not passive. Each oscillator in the network is coupled to its neighbours through the zero-point fluctuation field $D$. A deformation at one node shifts the equilibrium of its neighbours — like pressing a finger into a stretched membrane.

The mechanism is concrete:

1. The mass creates a local chiral imbalance: $\rho_L > \rho_R$ at the source.
2. The imbalance deforms the local torus — $\tau$ shifts from $\tau_0$.
3. The deformed oscillator is now slightly mismatched with its neighbours. The mismatch exerts a restoring force on adjacent oscillators, displacing their $\tau$ values.
4. Each displaced neighbour displaces the next. The perturbation $\delta\tau$ propagates outward as a wave on the moduli space, at the local speed $\upsilon \cdot \kappa$.

5. In the static limit, the propagation reaches equilibrium: $\nabla^2\kappa = g(\rho_L - \rho_R)$ — the Poisson equation. The $1/r$ falloff of the Newtonian potential is the static Green's function of this wave equation.

There is a deeper reason the perturbation resolves into a $1/r$ field rather than propagating indefinitely and re-equilibrating the entire universe. In a vacuum with zero energy there would be no restoring force: a single electron's chiral imbalance would tilt every adjacent oscillator, which would tilt the next, until the entire network settled at a new uniform $\kappa$. Gravity would not be local — it would be a one-time global rearrangement. The $\sim 10^{113}$ J/m³ of vacuum energy prevents this. Each oscillator is under enormous pressure to remain at $\kappa = 1$; the perturbation must fight this pressure at every step. The result is the $1/r$ decay: the field sustains a local imbalance near the source, but the vacuum's stiffness wins at distance. Newton and Einstein take the flat background as a boundary condition. In this framework, that boundary condition is earned — it is the dynamical equilibrium of a network held at $\kappa = 1$ by its own energy content.

The local propagation speed of $\kappa$-perturbations is $\upsilon \cdot \kappa$ — the same as the local speed of light, $c_{\text{eff}}$. In the vacuum ($\kappa = 1$) this is $\upsilon = c$. This is not a coincidence — it is necessary. The same vacuum density that sets $\upsilon$ also provides the stiffness that transmits $\kappa$. The medium that carries light carries gravity. The speed of gravitational waves equals the speed of light because both are signals in the same network, subject to the same local dilation.

Dynamic changes in $\kappa$ — a star exploding, two black holes merging — launch gravitational waves: ripples in $\tau$ propagating through the dipole network at $\upsilon \cdot \kappa$. These are the waves detected by LIGO [7]. In the $\tau$-plane (Figure 1), a gravitational wave is an oscillation of $\tau$ around $\tau_0$ — a small loop near the vacuum point.

# 12 The Toroidal Geometry of Gravity

The preceding sections established two gravitational parameters — $\kappa$ (dilation, sourced by the chiral difference) and $\upsilon$ (propagation speed, sourced by the chiral sum) — and showed that they reproduce known physics. The scalar field $D = \psi_L + i\psi_R$ is exact for photons — energy passing through the vacuum oscillator network without wrapping the torus. Here we make explicit the geometric structure of each vacuum oscillator: a two-radius torus at each point of spacetime, whose radii *are* the two gravitational parameters.

## 12.1 The Two-Radius Torus

At each spacetime point, the chiral dipole field lives on a torus $T^2$ parametrised by two radii:

- **The large radius $R$**: the circumference of the torus in the toroidal direction. This is set by the total chiral energy density $\rho_L + \rho_R$ and determines the baseline propagation speed $\upsilon$.
- **The small radius $r$**: the circumference of the torus in the poloidal direction. This encodes the local dilation field $\kappa$ and is deformed by the chiral energy *difference* $\rho_L - \rho_R$.

The propagation speed around the large circle is:

$$\upsilon = \frac{\mathcal{P}_\upsilon}{\sqrt{\rho_L + \rho_R}} \qquad \leftrightarrow \qquad R \tag{34}$$

The local dilation is:

$$\kappa = f(\rho_L - \rho_R) \qquad \leftrightarrow \qquad r \tag{35}$$

In the vacuum, both radii are at their equilibrium values: $R = R_0$ (set by $\rho_{\text{vac}}$, giving $v = c$) and $r = r_0$ (set by $\rho_L = \rho_R$, giving $\kappa = 1$). Flat spacetime is a torus at rest.

## 12.2 The Chiral Sign Flip

The key physical content is how the two chiral sectors deform the small radius:

- **Left-chiral energy (matter)** *pinches* the small circle: $r < r_0$, hence $\kappa < 1$. The coordinate propagation speed $c_{\text{eff}} = v \cdot \kappa$ decreases — light slows in a gravitational well (the Shapiro delay). By the principle of local invariance, rulers and clocks rescale with $\kappa$, so a local observer always measures $c$. This is a valley in the $\kappa$ landscape.
- **Right-chiral energy (antimatter)** *stretches* the small circle: $r > r_0$, hence $\kappa > 1$. The dilation is reversed — a hill in the $\kappa$ landscape. Test particles (made of matter, scaling with $\kappa$) roll away. This is gravitational repulsion.

The sign flip is not imposed — it is the geometry of the torus. A left-handed field winds one way around the poloidal circle; a right-handed field winds the other way. Same circle, opposite deformation.

| **Source** | **Effect on $r$** | **Effect on $\kappa$** | **Gravity** |
|---|---|---|---|
| Vacuum ($\rho_L = \rho_R$) | $r = r_0$ | $\kappa = 1$ | Flat — no curvature |
| Matter ($\rho_L > \rho_R$) | $r < r_0$ (pinch) | $\kappa < 1$ | Attractive — valley |
| Antimatter ($\rho_L < \rho_R$) | $r > r_0$ (stretch) | $\kappa > 1$ | Repulsive — hill |

## 12.3 Why Two Radii, Not One

A single extra dimension (Kaluza-Klein compactification) gives one modulus — one gravitational degree of freedom. A torus has two independent radii, and therefore two independent moduli. This is *exactly* the number needed:

- One modulus ($R$) for the *sum* $\rho_L + \rho_R$ — the propagation speed.
- One modulus ($r$) for the *difference* $\rho_L - \rho_R$ — the curvature.

A sphere ($S^2$) has only one radius. A torus ($T^2$) is the simplest compact surface with two. The gravitational structure of the Chiral Dipole Field — two parameters, two sources, two constants ($G$ and $\mathcal{P}_v$) — requires exactly the topology of a torus. Nothing simpler works. Nothing more complex is needed.

## 12.4 Connection to Established Compactification

The ingredients are individually well-known:

| **Concept** | **Status** | **Where** |
|---|---|---|
| Torus compactification | Published | Kaluza-Klein theory, string theory |
| Moduli fields controlling radii | Published | String phenomenology |
| Varying speed of light from extra dimensions | Published | VSL cosmologies, braneworlds |
| Chiral energy sourcing dilation | **New** | This paper (Gravitational Polarity Symmetry) |

| Concept | Status | Where |
|---|---|---|
| $R$ fixed as vacuum baseline, $r$ as local $\kappa$ | **New** | This paper |
| Left energy pinches $r$, right energy stretches $r$ | **New** | This paper |

What is original is the *specific assignment*: the large radius carries the vacuum energy scale and sets $c$; the small radius carries the chiral imbalance and produces gravity; and the two chiral sectors deform the small radius in opposite directions. This is the geometric realisation of the **Gravitational Polarity Symmetry** [8].

## 12.5 From Scalar to Spinor

The scalar field $D = \psi_L + i\psi_R$ is exact for photons — and the reason is physical, not approximate. The vacuum at each spacetime point is an electron-positron oscillator: a virtual $e^-e^+$ pair whose chiral structure sits on the torus. A photon is energy passing through this oscillator network. It excites the poloidal phase of each oscillator as it passes — the direction of excitation is the helicity:

- Counter-clockwise excitation → helicity $h = +1$ → left-circular photon (optics convention)
- Clockwise excitation → helicity $h = -1$ → right-circular photon

The photon traverses the toroidal direction — one pass through the large circle $R$ per oscillator node. This is what sets the propagation speed $v$: the time to cross each node is determined by $R$, and the speed of light is the rate at which this traversal propagates through the network. But the photon does not wrap the poloidal direction — the small circle $r$. It has no standing-wave structure on $r$, no winding number, no rest frame. This is why the scalar $D$ is exact: it captures the toroidal pass-through without needing the poloidal topology.

A massive excitation (electron, positron) is fundamentally different — it wraps *both* circles. The poloidal winding number determines the chirality. The toroidal winding contributes to the rest energy. Mass is topological: it is the energy cost of wrapping the small circle. An electron and a positron wrap in opposite poloidal directions — same energy, opposite chiral sign — and therefore source $\kappa$ with opposite signs.

The full chain from geometry to gravity:

| Poloidal winding | Helicity | Chiral sector | Particle | Gravity ($\boldsymbol{\kappa}$) |
|---|---|---|---|---|
| Counter-clockwise | $h = +1$ | Left ($\psi_L$) | Left-circular photon / Electron | Attractive (pinch $r$) |
| Clockwise | $h = -1$ | Right ($\psi_R$) | Right-circular photon / Positron | Repulsive (stretch $r$) |

The Dirac equation's four solutions at each momentum map directly onto the four winding modes of a spinor on $T^2$: two toroidal directions × two poloidal directions. The $\pm E$ branches are the two poloidal windings. The spin-up/spin-down are the two toroidal orientations. The $\pi/2$ phase structure (Section 2) is the geometric angle between the two circles of the torus.

This is why the scalar model works as well as it does: the essential chiral structure — two components at $\pi/2$, counter-rotating states, signed gravitational source — is already present in the torus topology. The scalar $D$ is the projection of the toroidal spinor onto the poloidal plane.

## 12.6 The Complex Poloidal Modulus

A torus is characterised in mathematics not by two real radii but by a single complex number — the modular parameter

$$\tau = \frac{\alpha}{2\pi} + i\frac{R}{r}, \tag{36}$$

where $\alpha$ is the twist angle between the two circles and $R/r$ is the aspect ratio. The modular parameter lives in the upper half of the complex plane ($\operatorname{Im}\tau > 0$), and its complex structure is exactly what the source–response problem requires.

**The identification.** The two components of $\tau$ map to the two gravitational parameters:

1. $\operatorname{Im}\tau = R/r$ — the aspect ratio. Since $R \approx R_0$ is pinned by the vacuum, changes in $\operatorname{Im}\tau$ track the poloidal radius $r$. The dilation field is the normalised poloidal radius:

$$\kappa = \frac{r}{r_0} = \frac{\operatorname{Im}\tau_0}{\operatorname{Im}\tau}, \tag{37}$$

where $\tau_0 = iR_0/r_0$ is the vacuum modular parameter — purely imaginary, zero twist.

1. $\operatorname{Re}\tau = \alpha/(2\pi)$ — the twist. A left-chiral mode, winding counter-clockwise around the small circle, advances its toroidal phase by $\alpha$ per lap of the large circle. A right-chiral mode retards it. In the vacuum, equal populations cancel:

$$\rho_L = \rho_R \implies \operatorname{Re}\tau = 0 \implies \tau = \tau_0 \qquad \text{(purely imaginary).} \tag{38}$$

A chiral imbalance tilts $\tau$ off the imaginary axis. Matter twists right; antimatter twists left.

**Source–response matching.** The source is complex: $D = \psi_L + i\psi_R$. The response is now also complex: $\tau$. Their structures are parallel:

| **Complex part** | **Source $D = \psi_L + i\psi_R$** | **Response $\tau$** |
|---|---|---|
| Real part | $\psi_L$ — left-chiral amplitude | Twist — net chiral winding |
| Imaginary part | $\psi_R$ — right-chiral amplitude | $R/r$ — torus shape $\to \kappa$ |
| Modulus | Total field strength | Overall gravitational scale |
| Vacuum value | $\psi_L = \psi_R$ (balanced) | $\tau_0 = iR_0/r_0$ (untwisted, $\kappa = 1$) |

The $i$ that separates the two chiral sectors in the source field is the same $i$ that separates twist from shape in the torus. This is not a convention — it is the complex structure of $T^2$ itself.

**Visualising gravity.** The gravitational state at each spacetime point is a point $\tau$ in the upper half-plane. Gravity becomes motion on this plane:

- **Flat spacetime**: every spatial point maps to $\tau_0$ — one dot on the imaginary axis.
- **Approaching a star** (left-chiral excess): $r$ shrinks (pinch), so $\operatorname{Im}\tau$ increases — *up*. The net twist is positive — *right*. The trajectory sweeps up and to the right from $\tau_0$.
- **Approaching an antimatter source** (right-chiral excess): $r$ grows (stretch), so $\operatorname{Im}\tau$ decreases — *down*. The twist is negative — *left*. The trajectory sweeps down and to the left.
- **Singularity** ($\kappa \to 0,\ r \to 0$): $\operatorname{Im}\tau \to \infty$, the top of the half-plane. The poloidal circle collapses — the Schwarzschild singularity of GR, but at infinite geodesic distance in the $\tau$-plane: unreachable (Section 12.7).
- **Extreme repulsion** ($\kappa \to \infty$, $r \to \infty$): $\operatorname{Im}\tau \to 0$, the real axis. The torus degenerates the other way — the small circle overwhelms the large. A white hole would require right-chiral

energy concentrated enough to form a repulsive horizon — but antimatter is self-repulsive and disperses under its own gravity. White holes are dynamically forbidden.

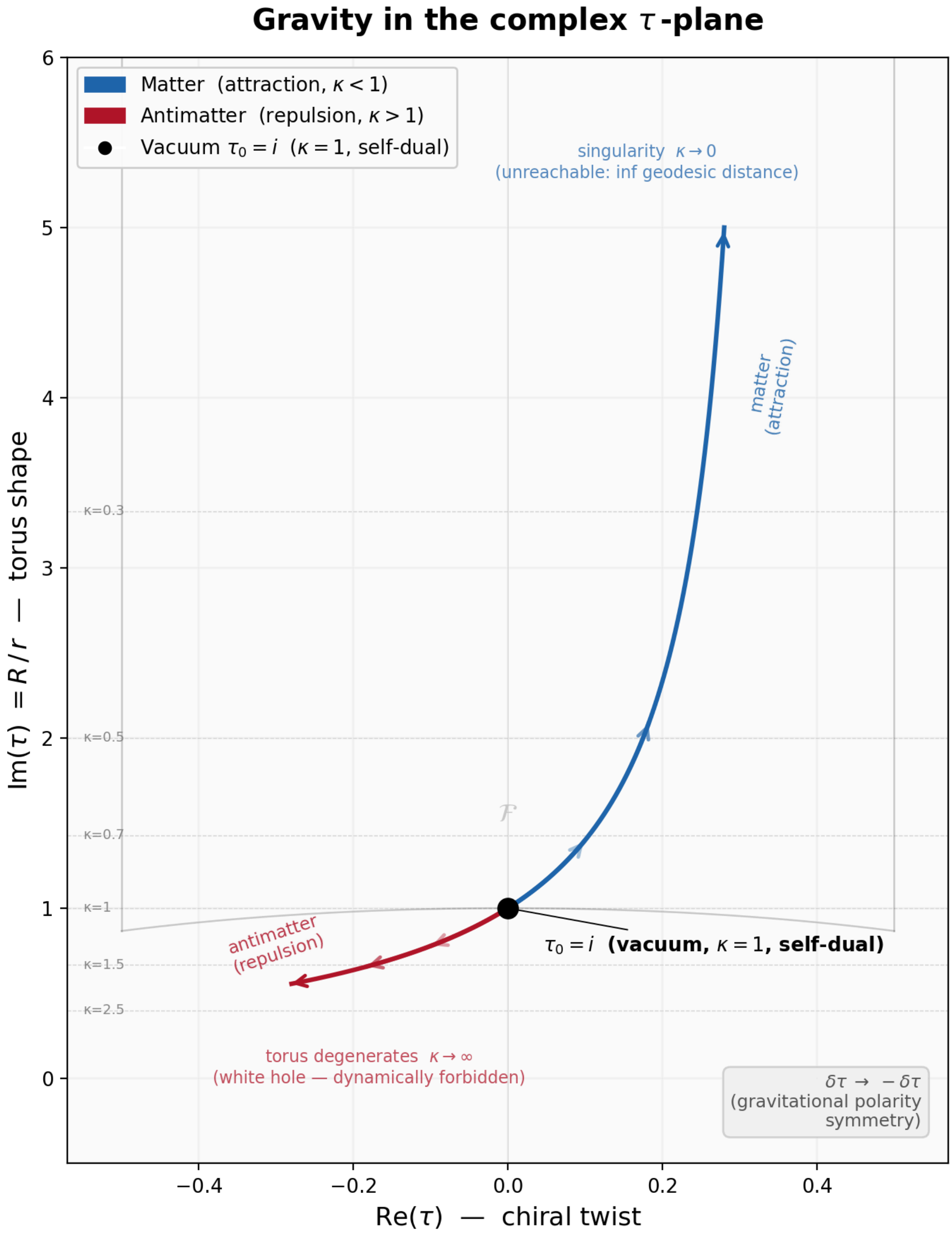


Figure 1: Gravity in the complex $\tau$-plane. The vacuum state $\tau_0 = i$ (black dot, $R = r$) sits on the imaginary axis at $\kappa = 1$. Approaching a matter source (blue, left-chiral excess) sweeps $\tau$ up and to the right — the poloidal circle pinches ($\kappa < 1$), attraction. Approaching an antimatter source (red, right-chiral excess) sweeps $\tau$ down and to the left — the poloidal circle stretches ($\kappa > 1$), repulsion. The two trajectories are exact mirror images under $\delta\tau \to -\delta\tau$: the gravitational polarity symmetry. Three source strengths are shown (strong to weak). The faint arcs outline the $\mathrm{SL}(2, \mathbb{Z})$ fundamental domain $\mathcal{F}$.

The gravitational polarity symmetry — the chiral sign flip $\psi_L \leftrightarrow \psi_R$ — acts on the $\tau$-plane as point reflection through the vacuum: $\delta\tau \to -\delta\tau$, where $\delta\tau \equiv \tau - \tau_0$. Matter and antimatter trajectories are exact mirror images. The vacuum is the fixed point of the symmetry.

Flat spacetime is a point. Gravity is a displacement. Matter and antimatter displace in opposite directions. The entire gravitational field of a source is a single curve in the $\tau$-plane — readable at a glance.

**Modular invariance.** The modular group $\mathrm{SL}(2,\mathbb{Z})$ acts on $\tau$ by Möbius transformations:

$$\tau \to \frac{a\tau + b}{c\tau + d}, \quad ad - bc = 1. \tag{39}$$

Two generators are physically transparent. The shift $\tau \to \tau + 1$ advances the twist by one full turn — physically trivial. The inversion $\tau \to -1/\tau$ *swaps the two circles*, exchanging $R \leftrightarrow r$ and therefore the speed channel $\leftrightarrow$ the curvature channel: the speed of light and gravity are *modular duals*. The self-dual point $\tau = i$ (a square torus, $R = r$) is a natural candidate for the vacuum value $\tau_0$ — a constraint that, if physical, would fix $R_0/r_0 = 1$ and link the two gravitational constants at the deepest level.

## 12.7 The Singularity That Cannot Be Reached

The $\tau$-plane is not a flat space. It carries the Poincaré metric — the natural hyperbolic metric on the upper half-plane:

$$ds^2 = \frac{|d\tau|^2}{(\mathrm{Im}\,\tau)^2}. \tag{40}$$

This metric is inherited from the torus: it is the unique Riemannian metric on the space of torus shapes that respects the modular group $\mathrm{SL}(2,\mathbb{Z})$. It is not imposed by hand — it is the kinetic term of the $\tau$-field.

The consequences for singularities are immediate.

In general relativity, a point mass creates a singularity at $r = 0$ where the metric diverges and geodesics terminate in finite proper time. The singularity is *reachable*. This is the central unsolved pathology of classical gravity.

In the chiral framework, the analogue of the singularity is $\kappa \to 0$: the small torus radius $r \to 0$, the dilation becomes total. In the $\tau$-plane, this corresponds to $\mathrm{Im}(\tau) = R/r \to \infty$. The geodesic distance from the vacuum state $\tau_0$ to the $\mathrm{Im}(\tau) = \infty$ boundary is:

$$d(\tau_0, \infty) = \int_{R_0/r_0}^{\infty} \frac{dy}{y} = \infty. \tag{41}$$

The singularity is at infinite geodesic distance. It is *unreachable*. No finite-energy perturbation of the $\tau$-field can reach it.

The mechanism is the Poincaré metric itself. As $\mathrm{Im}(\tau)$ grows, the metric shrinks — each further step in the imaginary direction costs less coordinate displacement but the same field-space effort. The $\tau$-field slows down logarithmically. The natural non-linear variable is $\ln\kappa = -\ln(\mathrm{Im}\ \tau/\ \mathrm{Im}\ \tau_0)$, which maps $\kappa \in (0,\infty)$ to $(-\infty, +\infty)$. The singularity at $\kappa = 0$ recedes to $\ln\kappa = -\infty$.

This is singularity resolution without:

- a discrete spacetime (loop quantum gravity),
- extended fundamental objects (string theory),

- a bounce from new physics at the Planck scale,
- any additional assumption beyond the geometry already established.

The $\tau$-plane figure (Figure 1) shows this directly. The matter trajectories (blue curves) sweep upward as $\kappa \to 0$ — but the Poincaré metric compresses the upper half-plane so that the boundary at infinity is never reached. The closer the field approaches total dilation, the more field-space distance remains. General relativity, working in real-valued metric components on a flat field space, has no mechanism to see this: its singularity is at finite distance.

The physicist sees a black hole. The $\tau$-field sees a mountain that grows faster than the climber can approach. This is the $\tau$-field's deepest structural secret — and, since the $\tau$-field is what gets quantised, it is the graviton's: it lives on a space that protects the universe from its own extremes.

## 12.8 Black Hole Interiors: The $\tau$-Map

The unreachability of the singularity has a stronger consequence than singularity resolution alone. It means the $\tau$-field provides a well-defined gravitational description at *every* point of spacetime — including the region that general relativity calls the black hole interior.

In GR, the event horizon is a one-way membrane. Beyond it, the radial coordinate becomes timelike, geodesics terminate at the singularity in finite proper time, and the theory provides no physical description of what happens at $r = 0$. The singularity is not a place — it is a breakdown of the mathematical framework. The interior of a black hole is, in the deepest sense, *unknown* in GR: the equations stop.

In the $\tau$-framework, the gravitational state at every point is a point $\tau$ in the upper half-plane — and the upper half-plane has no boundary at finite geodesic distance. As one moves inward from the event horizon toward the classical singularity ($r \to 0$), $\kappa$ decreases toward zero, and $\tau$ climbs upward in the half-plane. The field becomes extreme — $\mathrm{Im}(\tau) \gg 1$ — but it is everywhere defined, everywhere finite, everywhere smooth. The Poincaré metric ensures that the description never breaks down, because the "breakdown point" is at infinite distance.

The event horizon itself — located at $\kappa = 1/2$ in isotropic coordinates for the Schwarzschild case — is not special in the $\tau$-plane. It is an ordinary point, surrounded by ordinary points, with a particular value of $\mathrm{Im}(\tau)$. The one-way character of the horizon is a property of the *metric* derived from $\tau$ — specifically, the light cones tilt — not of $\tau$ itself. The underlying field is everywhere regular.

This opens a concrete possibility: given the non-linear extension of the $\tau$-field equations (the central open problem of Section 12), one could compute $\tau(x)$ throughout the entire interior of a black hole. The strong-field behaviour — what happens when $\delta\kappa \sim 1$, when the torus is maximally pinched — is encoded in the geometry of the upper half-plane with its Poincaré metric and $\mathrm{SL}(2, \mathbb{Z})$ symmetry. The natural non-linear variable is $\ln \kappa = -\ln(\mathrm{Im}\ \tau / \ \mathrm{Im}\ \tau_0)$, which never diverges at any finite point. The calculation is hard. The breakdown is gone.

What would one find? The framework makes a structural prediction: as $\kappa \to 0$, the torus is infinitely pinched — $r \to 0$ — and the dilation field climbs a hyperbolic mountain that grows faster than any approach. The "singularity" is replaced by an asymptotic regime: infinite time dilation, vanishing local propagation speed, but no point where the description fails. The interior of a black hole, in this picture, is not a mystery. It is the high-altitude region of the $\kappa$-landscape — extreme, but mappable.

# 13 Matching to Established Physics

## 13.1 What the Framework Reproduces

| Domain | Result | Status |
|---|---|---|
| Maxwell | Plane-wave solutions, two circular polarisations, $\omega = \lvert k \rvert c$, $\pi/2$ $\boldsymbol{E}$–$\boldsymbol{B}$ phase | Exact match (Section 4) |
| Dirac | $\pm E$ spectrum = chirality; massless and massive cases | Exact match (Section 2) |
| Klein–Gordon | $\Box D = 0$ — massless wave equation | Exact match |
| Lorentz invariance | $\lvert 0 \rangle$ Lorentz-invariant; $\mathcal{L}$ is a scalar; no preferred frame | Exact match |
| Casimir effect | $\langle D \rangle = 0$ but $\langle \lvert D \rvert^2 \rangle \neq 0$ — zero-point fluctuations real | Consistent |
| Newtonian gravity | $\nabla^2 \kappa = g\rho_{\text{matter}}$ reproduces Poisson equation | Exact match |
| Newtonian potential + redshift | $\kappa(r) = 1 - GM/(c^2 r)$ reproduces $g_{tt}$ | Exact match |
| Full weak-field metric ($g_{rr}$) | Requires spatial gradient structure of $\tau$-field | Open — needs non-linear extension |
| Vacuum flatness | $\rho_L^{\text{vac}} = \rho_R^{\text{vac}} \to \nabla^2 \kappa = 0 \to$ flat spacetime | Exact match |
| Speed of light | $\upsilon = \mathcal{P}_v / \sqrt{\rho_{\text{vac}}}$ — explained, not postulated | New result |
| Toroidal geometry | Two radii $R, r$ map to $\upsilon, \kappa$ — two gravitational d.o.f. | New result (Section 12) |
| Quantum gravity | $\tau$-field quantisation; superposition, entanglement, path integral | New result (Section 14) |

## 13.2 Where the Framework Extends GR

| Prediction | GR says | Framework says |
|---|---|---|
| Vacuum curvature | Divergent (predicts collapse) | Zero (chiral balance) |
| Speed of light origin | Fundamental constant | Set by vacuum energy density |
| Antimatter gravitational source | Attractive (same as matter) | Repulsive (opposite chiral sign) |
| Dark energy | Cosmological constant $\Lambda$ | Diffuse antimatter background |
| Baryon asymmetry | Unknown creation mechanism | Selection effect: matter clumps, antimatter doesn't |

The framework does not contradict GR in any experimentally tested Newtonian-limit regime. It extends GR by providing a mechanism for vacuum flatness and by splitting the gravitational source into two chiral components. Whether it reproduces the post-Newtonian corrections — Mercury's precession, light deflection, the Shapiro delay — depends on the spatial metric $g_{rr}$ emerging from the $\tau$-field, which is an open problem.

# 14 Quantum Gravity in the Chiral Framework

The traditional obstacle to quantum gravity is that the gravitational field — the metric $g_{\mu\nu}$ — is not a quantum field in the conventional sense: it cannot be expanded in creation and annihilation operators on a fixed background, because it *is* the background. Eight decades of effort to quantise $g_{\mu\nu}$ directly have produced deep mathematics but no finite, predictive theory.

In the present framework, gravity is not the metric. Gravity is a pair of scalar fields — $\kappa(x)$ (dilation, from $\rho_L - \rho_R$) and $\upsilon(x)$ (propagation speed, from $\rho_L + \rho_R$) — and these fields are sourced by the chiral vacuum, which is already a quantum field. The metric is *derived* from $\kappa$ and $\upsilon$; it is an output, not an input. **The fields that *produce* gravity are ordinary quantum fields living on the torus modular parameter $\boldsymbol{\tau}$** (Section 12.6). They can be quantised by the standard rules.

This does not automatically solve every problem of quantum gravity. But it removes the central conceptual obstruction. In standard approaches, the background must be assumed — typically Minkowski spacetime — and the justification for this assumption is pragmatic, not physical. Here, flat spacetime is not assumed. It is the derived ground state: $\rho_L = \rho_R$ gives $\kappa = 1$ everywhere (Section 7). The $\tau$-field is a quantum field on this derived background, valued in a well-defined target space ($\mathcal{H}$) with a well-defined symmetry group ($\mathrm{SL}(2, \mathbb{Z})$). Perturbative expansion around $\tau_0$ is not an approximation to an unknown exact theory — it is expansion around the physical vacuum.

In short: the vacuum is flat by chiral balance. Therefore Minkowski spacetime is the justified, physical background. $\tau(x)$ is a quantum field on that background. Standard perturbative QFT applies.

For the QFT reader, this is a change of ontology, not of method. We keep the full machinery — operator algebra, propagators, renormalisation logic, and path integrals — but we move the fundamental degrees of freedom from a pre-given geometric stage to the chiral substrate fields that generate geometry. In this sense, the stage becomes the players: **spacetime shape is a collective state of $\boldsymbol{\tau}$, $\boldsymbol{\kappa}$, and $\boldsymbol{\upsilon}$**, not an external object to quantise directly. This perspective is most natural in the Planck regime, where a fixed 3D geometric picture loses operational meaning and field-state variables on moduli space remain well-defined.

## 14.1 Superposition of Gravitational States

In GR, "superposition of metrics" is meaningless — two metrics cannot be added. But the modular parameter $\tau$ is a complex number, and complex numbers *can* be superposed. A quantum state of the gravitational field at a spacetime point is a wave function $\Psi(\tau)$ on the upper half-plane:

$$|\mathrm{gravity}\rangle = \iint \mathcal{D}\tau \, \Psi(\tau) \, | \, \tau\rangle \tag{42}$$

The vacuum is a coherent state sharply peaked at $\tau_0$. A massive particle creates a perturbation $\delta\tau$ that can be in a quantum superposition — just as the position of the particle itself can be.

**Schrödinger's star.** Consider a mass in a spatial superposition: half here, half there. In GR, the stress-energy tensor is in superposition, and one must ask what the "metric of a superposition" means — an ill-defined question. In the chiral framework, the mass sources a chiral imbalance $\rho_L - \rho_R$ at two locations simultaneously. The modular parameter $\tau(x)$ is in a superposition of two dilation profiles:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\tau_{\text{here}}(x)\rangle + |\tau_{\text{there}}(x)\rangle) \tag{43}$$

Each branch is a well-defined $\tau$-field on the upper half-plane. The superposition is a superposition of $\tau$-fields — mathematically identical to the superposition of any other quantum field. The gravitational field inherits quantum mechanics from its source, with no new axioms required.

## 14.2 Gravitational Entanglement

If the gravitational field is a quantum field valued in $\tau$, then two spatially separated regions can be gravitationally entangled:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\tau_A\rangle\ |\tau_B\rangle + |\tau'_A\rangle\ |\tau'_B\rangle) \tag{44}$$

where $\tau_A$ and $\tau_B$ are the modular parameters at regions $A$ and $B$. The dilation fields at $A$ and $B$ are correlated — measuring $\kappa$ at $A$ collapses $\kappa$ at $B$. This is gravitational entanglement in a precise, operational sense: it is entanglement of two complex numbers, not of two metrics.

A holographer would read this entangled state as an ER bridge: the $\mathrm{SL}(2,\mathbb{Z})$ moduli space and Weil-Petersson action already contain the topology that the ER=EPR conjecture requires [9].

## 14.3 Path Integral over Moduli

This approach has precedent: Weinberg [10] showed that GR follows entirely from a massless spin-2 field on flat spacetime, Donoghue [11] established it as a consistent EFT below the Planck scale, and Jacobson [12] and Verlinde [13] derived the Einstein equation from thermodynamics — each eroding the assumption that the metric must be quantised directly. What the present framework adds is a concrete identification of the underlying degrees of freedom: $\tau$, sourced by chiral energy, with the $\mathrm{SL}(2,\mathbb{Z})$ symmetry that string theory's modular invariance requires. The metric emerges; $\tau$ is what gets quantised.

The partition function of quantum gravity in this framework is a path integral over $\tau$-field configurations:

$$Z = \int \mathcal{D}\tau(x)\, e^{iS[\tau]} \tag{45}$$

where the action $S[\tau]$ is a functional of the modular parameter field. The natural kinetic term is the Weil-Petersson metric on moduli space:

$$S_{\text{kin}} = \int d^4x\, \frac{|\partial_\mu \tau|^2}{(\text{Im }\tau)^2} \tag{46}$$

This is the standard non-linear sigma model with target space $\mathcal{H}$. Such models are well-studied, ultraviolet-finite in two dimensions, and asymptotically free. In four dimensions, the theory is non-renormalisable by power counting — the same obstruction as pure GR — but with a crucial difference: the target space $\mathcal{H}$ has discrete symmetries ($\mathrm{SL}(2,\mathbb{Z})$) that constrain the UV completion. String theory's modular invariance enters not as an external requirement but as the internal symmetry of the gravitational field itself.

The potential term comes from the source — the chiral energy density:

$$S_{\text{source}} = \int d^4x \, V(\tau, \rho_L, \rho_R) \tag{47}$$

where $V$ penalises deviations of $\tau$ from the value dictated by the local $\rho_L, \rho_R$. The vacuum ($\rho_L = \rho_R$) is the minimum of $V$ at $\tau = \tau_0$. Quantum fluctuations of $\tau$ around this minimum are the graviton — developed fully in the next section.

## 14.4 The Gravitational Double Slit

The gravitational double slit is the sharpest test of whether gravity is quantum — and the only framework in which it is a well-posed question. In GR the question cannot even be formulated: the Einstein equations are non-linear, and a "superposition of metrics" has no mathematical meaning. The COW experiment [14] confirmed that a quantum test particle accumulates gravitational phase in a classical field (the *response* side); the double slit probes the *source* side — whether the $\kappa$-landscape is itself a quantum object when its source is in superposition.

## 14.5 What Quantum Mechanics Can Now Do

| **Quantum operation** | **Applied to $\tau$** | **Physical meaning** |
|---|---|---|
| Superposition | $\alpha \|\tau_1\rangle + \beta \|\tau_2\rangle$ | Gravity in two states at once — mass in spatial superposition |
| Measurement | Collapse of $\Psi(\tau)$ | Decoherence selects a classical metric — spacetime emerges |
| Entanglement | $\|\tau_A \tau_B\rangle + \|\tau'_A \tau'_B\rangle$ | Non-local gravitational correlations — ER=EPR candidate |
| Uncertainty | $\Delta(\text{Re}\ \tau) \cdot \Delta(\text{Im}\ \tau) \geq 1/2$ | Twist-shape uncertainty — cannot know both $\kappa$ and chiral source precisely |
| Tunnelling | $\tau$ jumps across barrier in $V(\tau)$ | Topology change — baby universe nucleation |
| Interference | Two $\tau$-paths contribute to amplitude | Gravitational double slit — COW-type experiments |
| Vacuum fluctuations | $\langle \delta\tau \, \delta\bar{\tau} \rangle \neq 0$ | Zero-point fluctuations of curvature — gravitational Casimir effect |

Every tool of quantum field theory — Feynman diagrams, renormalisation group, anomalies, dualities — applies directly to the $\tau$-field. The gravitational field is a quantum field on a background that the theory itself derives. No external assumption of flatness is needed — the chiral vacuum provides it.

# 15 The Graviton

The graviton — the quantum of the gravitational field — has been sought since the 1930s. In the standard approach, it is a massless spin-2 excitation of the metric tensor $g_{\mu\nu}$. But $g_{\mu\nu}$ is the background, and quantising the background has resisted eight decades of effort. In the present framework, the graviton is not a quantum of the metric. It is a quantum of the torus shape.

## 15.1 What It Is

The gravitational state at each spacetime point is encoded in the modular parameter $\tau$ (Section 12.6). The torus is the *background* — the vacuum structure that is always present at every point, sitting at $\tau_0$. The graviton is not the torus. It is the propagating adjustment between nodes: when a mass deforms the torus at one point, the mismatch with neighbouring nodes propagates outward as a $\delta\tau$-wave, and each quantum of that wave is a graviton. The torus is to the graviton as the crystal lattice is to the phonon — the medium, not the excitation.

The vacuum sits at $\tau_0$ — a minimum of the potential $V(\tau)$. A graviton is a small oscillation of $\tau$ around this minimum:

$$\tau(x) = \tau_0 + \delta\tau(x) \tag{48}$$

The perturbation $\delta\tau$ is a complex field — it has two real components:

- $\delta(\operatorname{Re}\tau)$: a twist oscillation — the chiral imbalance fluctuates.
- $\delta(\operatorname{Im}\tau)$: a shape oscillation — the torus aspect ratio fluctuates, and with it $\kappa$.

These are the two polarisation states of the graviton. In the linearised theory, they propagate independently and at the same speed — $v = c$ — because both are excitations of the same vacuum network.

## 15.2 Why It Is Massless

The graviton is massless because modular symmetry forbids a mass term. To see why, note that $\mathrm{SL}(2,\mathbb{Z})$ acts on $\tau$ by Möbius transformations:

$$\tau \to \frac{a\tau + b}{c\tau + d}, \quad ad - bc = 1, \quad a, b, c, d \in \mathbb{Z} \tag{49}$$

This is not a linear shift — it is a non-linear reparametrisation of the upper half-plane. A mass term $m^2\ |\delta\tau|^2$ would single out a preferred scale in $\tau$-space, breaking modular invariance: under $\tau \to -1/\tau$, the "distance" $|\delta\tau|$ transforms non-trivially ($|\delta\tau| \to |\delta\tau|\ /\ |\tau|^2$), so a quadratic potential is not modular-invariant. More generally, any polynomial in $\tau$ fails — the only functions of $\tau$ that respect $\mathrm{SL}(2,\mathbb{Z})$ are modular forms, and the lowest-weight modular-invariant potential has a flat minimum at the self-dual point $\tau_0 = i$, where $\tau_0 = -1/\tau_0$. At this point the curvature of $V(\tau)$ in the modular-invariant metric vanishes — there is no mass gap.

The argument parallels the photon: a gauge symmetry ($U(1)$ there, modular invariance here) protects the excitation from acquiring mass. But the mechanism is different. For the photon, gauge invariance forbids $m^2 A_\mu A^\mu$ because it is not gauge-invariant. For the graviton, modular invariance forbids $m^2\ |\delta\tau|^2$ because the Möbius action is non-linear — there is no modular-invariant quadratic form on the $\tau$-field.

The graviton propagates at $v = c$ with dispersion relation $\omega = |\boldsymbol{k}|\ c$ — the same as the photon, for the same reason: both are gapless excitations of the chiral vacuum. This is not a postulate. It is a consequence of the modular symmetry of the torus.

## 15.3 The Spin of the Graviton

**In this framework.** The fundamental gravitational field is $\tau$ — a complex scalar on the upper half-plane. A quantum of the perturbation $\delta\tau$ is therefore a spin-0 excitation. It has two real components ($\delta(\mathrm{Re}\,\tau)$ and $\delta(\mathrm{Im}\,\tau)$), propagates at $v = c$, and is protected from acquiring mass by modular invariance. This is the graviton of the chiral framework: a scalar quantum of the torus modular parameter.

**In GR.** The standard expectation is spin-2. This comes from a different starting point: linearising the Einstein equations gives a metric perturbation $h_{\mu\nu}$, which is a symmetric rank-2 tensor. The quantum of a rank-2 tensor field carries spin 2. GR has no deeper field — $h_{\mu\nu}$ is fundamental, so spin-2 is the only answer available.

**Why both are right.** The two answers are not in conflict. In this framework, the metric is not fundamental — it is a composite, built bilinearly from $\tau$:

$$h_{\mu\nu} \sim \frac{\partial_\mu \tau \, \partial_\nu \bar{\tau}}{(\mathrm{Im}\ \tau)^2} \tag{50}$$

The metric is quadratic in $\tau$, just as the electromagnetic stress tensor is bilinear in $F_{\mu\nu}$. Two derivatives, two indices — the composite is rank-2, but the underlying excitation is scalar. GR sees the emergent metric and correctly identifies spin-2. The chiral framework sees the underlying field and identifies spin-0. Both are observing the same object at different levels of description.

The analogy is exact: in condensed matter, the fundamental excitations of a lattice are scalar phonons, but the effective graviton in analogue gravity models appears as spin-2 — because the emergent metric is a composite of the underlying scalar field. The metric is to $\tau$ as pressure is to atoms.

**The degree-of-freedom test.** This two-level picture is self-consistent only if the counts match. In $d$ spacetime dimensions, a massless spin-2 particle has

$$N_{\mathrm{grav}} = \frac{d(d-3)}{2} \tag{51}$$

physical polarisations: zero in $d = 3$, two in $d = 4$, five in $d = 5$, nine in $d = 6$. A complex scalar field always has exactly two real components, regardless of dimension. These coincide only at $d = 4$. **Four-dimensional spacetime is the only arena in which a single complex modular parameter accounts for all gravitational degrees of freedom — no modes left over, none missing.** The two real components of $\delta\tau$ map exactly onto the two helicity states of the spin-2 graviton. In any other dimension, the picture breaks: either the metric has more degrees of freedom than $\tau$ can supply, or the scalar has too few to explain what is observed.

**The prediction.** Gravitational radiation has exactly two polarisation states — the two real components of $\delta\tau$. No scalar or vector modes exist, because the $\tau$-field has no additional degrees of freedom to source them. This matches LIGO [7]: two tensor polarisations, nothing else. The framework predicts that no future detector will find scalar gravitational radiation.

## 15.4 The Graviton as Landscape Distributor

**The graviton does not mediate a force between two particles. It distributes the dilation field.**

When a mass appears at a point — a left-chiral excess $\rho_L > \rho_R$ — it pinches the local torus: $\tau$ shifts from $\tau_0$, $\kappa < 1$. But the perturbation does not stay local. The mismatch between the deformed oscillator and its neighbours propagates outward through the vacuum network as a $\delta\tau$-wave, at speed $v = c$ (Section 12.6). Each quantum of this wave is a graviton. The graviton carries the information: "at the source, $\kappa$ has changed" — and it writes this change into the dilation field at every point it reaches.

In the static limit, the sum of all exchanged gravitons builds the equilibrium landscape: $\nabla^2\kappa = g(\rho_L - \rho_R)$, with the $1/r$ profile as its Green's function. In the dynamic limit — a star exploding, two black holes merging — the gravitons propagate as the wavefront that LIGO detects.

What matters is not a two-body force but a one-body question: what value of $\kappa$ does a given source distribute?

- Matter ($\rho_L > \rho_R$) builds $\kappa < 1$: a valley in the dilation landscape.
- Antimatter ($\rho_L < \rho_R$) builds $\kappa > 1$: a hill in the dilation landscape.
- The vacuum ($\rho_L = \rho_R$) gives $\kappa = 1$: flat.

Every particle with positive energy — matter or antimatter — follows the gradient of $\kappa$. This is the equivalence principle: geodesic motion depends on total energy, not on chirality. All particles roll into valleys and away from hills. ALPHA-g [15] confirmed this: antihydrogen falls toward Earth because it has positive energy and the Earth is a valley ($\kappa < 1$).

The source side carries a sign — $\kappa$ is sourced by $\rho_L - \rho_R$ — but the response side is universal: every form of energy responds to the gradient of $\kappa$ in the same way. The graviton distributes a dilation perturbation whose sign is set by the source's chirality, and whose response is governed by the equivalence principle.

The consequence is landscape: matter builds valleys, antimatter builds hills, and everything rolls downhill. Antimatter cannot gravitationally condense because the hill it distributes pushes away the very matter — and antimatter — that might gather around it. This is the structural origin of the cosmological sorting: matter clumps, antimatter disperses.

## 15.5 Signed Source, Unsigned Response

The source–response asymmetry deserves emphasis, because it is a structure that has no precedent in particle physics.

In every other fundamental interaction, either both sides are signed or neither is:

| **Interaction** | **Carrier** | **Source side** | **Response side** |
|---|---|---|---|
| Electromagnetism | Photon (neutral) | Charge $\pm q$ — signed | Charge $\pm q$ — signed |
| Weak force | $W^{\pm}$ (charged) | Weak isospin — signed | Weak isospin — signed |
| Strong force | Gluon (colour-charged) | Colour — signed | Colour — signed |
| GR gravity | Graviton (neutral) | $T_{\mu\nu} \geq 0$ — unsigned | Universal — unsigned |
| **Chiral gravity** | Graviton ($\delta\tau$, neutral) | $\rho_L - \rho_R$ — **signed** | Universal — **unsigned** |

In electromagnetism, sign appears on *both* sides: opposite charges attract, like charges repel. The force law $F \propto q_1 q_2 / r^2$ contains the *product* of two signs. In the weak and strong forces, the same pattern holds: the carrier sees the sign of the responder as well as the sign of the source.

In general relativity, neither side is signed. The stress-energy tensor $T_{\mu\nu}$ is non-negative for classical matter, and the response — geodesic motion — is universal. There is no sign anywhere. This is why GR cannot distinguish matter from antimatter gravitationally.

The chiral framework occupies a third position. The source writes a signed perturbation into the dilation field: a chiral excess $\rho_L > \rho_R$ lowers $\kappa$ (a valley); $\rho_L < \rho_R$ raises it (a hill); the balanced vacuum leaves $\kappa = 1$ (flat). The graviton carries this signed $\delta\kappa$ outward through the network. Unlike a photon — whose $\boldsymbol{E}$ and $\boldsymbol{B}$ fields travel with it in a single propagation direction and write no update into the surrounding vacuum — the graviton from a point source expands as a spherical wave, reaching every node of the vacuum network simultaneously: closer in spirit to the field radiated by an antenna than to any single emitted photon. It does not interact with particles or photons directly — its only job is to update the local dilation value at each node it reaches. Once the update is written, the dilation field has a gradient, and that gradient is what moves things:

$$\vec{a} = -v^2 \nabla(\delta\kappa) \tag{52}$$

When $\delta\kappa < 0$ is written into a region, the local $\kappa$ decreases and the gradient points inward — anything present in that region flows toward the source along the steepened landscape. When $\delta\kappa > 0$ is written, the gradient points outward — things flow away. The dilation landscape does the moving; the graviton only delivers the update. No property of what is being moved enters at any step — the direction of flow is determined entirely by the sign the source wrote into the field. This is what "unsigned response" means in dilation-field language: the outcome's sign lives in the field, not in the particle.

This asymmetry is not imposed — it emerges from the structure of the $\tau$-field. The source equation $\nabla^2\kappa = (4\pi G)/v^2(\rho_L - \rho_R)$ is linear in the *signed* chiral difference. The response equation depends on *total* energy, which is always positive. Sign enters through the Dirac equation's chiral structure (Section 2); absence of sign on the response side is the equivalence principle.

The signed source has one further consequence: **the graviton has two species, valley and hill.** The sign of $\delta(\operatorname{Im}\tau)$ is conserved during propagation and is determined not by the absolute chirality of the source but by the **sign of the change** in local chiral density — $\delta(\rho_L - \rho_R)$ — at the moment of emission. When the local left-chiral density **rises** ($\delta(\rho_L - \rho_R) > 0$), a valley graviton is emitted — a quantum with $\delta(\operatorname{Im}\tau) > 0$, carrying "kappa decreases ahead"; everything it reaches is attracted toward that region. When the local left-chiral density **falls** ($\delta(\rho_L - \rho_R) < 0$), a hill graviton is emitted — $\delta(\operatorname{Im}\tau) < 0$, carrying "kappa increases ahead"; everything is repelled. The two species are related by the gravitational polarity symmetry $\delta\tau \to -\delta\tau$; they are, in the QFT sense, the graviton and antigraviton.

A static mass sustains a permanent left-chiral excess — the change is always positive, so it sources valley gravitons continuously and builds the equilibrium valley landscape. A passing left-circular photon is more subtle: as it **enters** a node the local left-chiral density momentarily rises ($\delta(\rho_L - \rho_R) > 0$) — a valley graviton is emitted; as it **departs**, the density returns to vacuum ($\delta(\rho_L - \rho_R) < 0$) — a hill graviton follows. The photon's gravitational imprint is therefore a dipole pair, not a monopole: a valley signal at the leading edge, a hill signal at the trailing edge.

**The gravitational signature of a beam of light depends on its polarisation — but each polarisation state produces both species in sequence as it moves through the network, not one exclusively.**

| **Species** | $\boldsymbol{\delta(\mathrm{Im}\,\tau)}$ | **Effect at receiver** | **Emitted when** |
|---|---|---|---|
| Valley graviton | $> 0$ | $\kappa$ decreases — attraction | Chiral density rising ($\delta(\rho_L - \rho_R) > 0$) |
| Hill graviton | $< 0$ | $\kappa$ increases — repulsion | Chiral density falling ($\delta(\rho_L - \rho_R) < 0$) |

In QFT terms, achieving this pattern — signed dilation source, sign-blind landscape response — is notoriously difficult. A scalar mediator coupled to a conserved charge naturally gives sign on both sides (Yukawa). A tensor mediator coupled to $T_{\mu\nu}$ gives sign on neither side (GR). The $\tau$-field achieves the third option because it couples to the *difference* of two positive-definite densities — a signed quantity built from unsigned parts — while the response is governed by the *gradient* of the resulting landscape, which is sign-blind. The chiral framework does not engineer this asymmetry. It inherits it from the Dirac equation.

## 15.6 The Two Polarisations and LIGO

General relativity predicts that gravitational waves have two independent polarisation states, conventionally called $h_+$ and $h_\times$. They stretch and squeeze space along orthogonal axes. LIGO has measured both [7].

In the $\tau$-plane, these polarisations have a concrete identity:

| **GR polarisation** | $\boldsymbol{\tau}$**-plane oscillation** | **Physical content** |
|---|---|---|
| $h_+$ | $\delta(\mathrm{Im}\,\tau)$ — shape mode | The torus aspect ratio oscillates — $\kappa$ oscillates — rulers stretch and compress symmetrically |
| $h_\times$ | $\delta(\mathrm{Re}\,\tau)$ — twist mode | The chiral balance oscillates — the torus twists back and forth — rulers stretch and compress at $\pi/4$ |

The $\pi/4$ rotation between $h_+$ and $h_\times$ is the $\pi/2$ phase between $\mathrm{Re}\,\tau$ and $\mathrm{Im}\,\tau$ — the same $\pi/2$ that separates $\psi_L$ and $\psi_R$ in the chiral dipole field (Section 2), halved because the metric is quadratic in $\tau$. The factor of two between the graviton's spin (2) and the photon's spin (1) traces directly to this: the metric takes two copies of $\tau$ where the electromagnetic field takes one copy of $D$.

This relationship runs in both directions. If we start from the LIGO data — two tensor polarisations at $\pi/4$ and nothing else — and ask what vacuum field could produce them, the answer is tightly constrained:

- A real scalar field has one degree of freedom $\to$ one polarisation. Not enough.
- A vector field has three $\to$ scalar and vector modes in addition to tensor. Too many — and not observed.
- A complex scalar has exactly two real degrees of freedom. If the observable is bilinear in the field ($h_{\mu\nu} \sim \partial_\mu\tau\,\partial_\nu\bar{\tau}/(\mathrm{Im}\;\tau)^2$), the two components produce exactly two tensor polarisations with no scalar or vector admixture.

The $\pi/4$ angle between $h_+$ and $h_\times$ is the direct experimental signature of the $\pi/2$ internal phase of the source field (halved by the quadratic metric). A $\pi/2$ internal phase between two real components is the definition of complex structure — and a complex vacuum oscillator whose two components are the two chiral sectors is, by construction, a chiral oscillator. **The graviton does not happen to fit a chiral source. LIGO's polarisation pattern *requires* it.**

## 15.7 What LIGO Detected

LIGO detected gravitational waves from merging black holes and neutron stars. In the standard interpretation, these are ripples in the metric tensor propagating at $c$.

In the present framework, LIGO detected $\tau$-waves — oscillations of the torus modular parameter propagating through the chiral vacuum network at $v = c$. The strain $h = \Delta L/L$ measured by the interferometer is the local value of $\delta\kappa$ — the perturbation of the dilation field. LIGO's two arms respond to the two components of $\delta\tau$: shape and twist.

The detection is the same. The physics is different:

| **Standard GR** | **Chiral framework** |
|---|---|
| Gravitational wave = metric ripple | Gravitational wave = $\tau$-wave in the vacuum network |
| Propagation medium: spacetime itself | Propagation medium: chiral dipole network — spacetime is a **collective state** of this quantum substrate, not a pre-given arena |
| Speed = $c$ by postulate | Speed $= v = c$ because the same vacuum density sets both |
| Two polarisations from symmetric traceless $h_{\mu\nu}$ | Two polarisations from $\mathrm{Re}\,\tau$ (twist) and $\mathrm{Im}\,\tau$ (shape) |
| Graviton: quantum of $g_{\mu\nu}$ (cannot be consistently quantised) | Graviton: quantum of $\tau$ (standard QFT on derived background) |

The last row is the point. LIGO has detected the classical limit of a field that *can* be quantised. The graviton is not hypothetical in this framework — it is the quantum of a field whose classical waves have already been measured.

## 15.8 The Graviton and the Photon

The graviton and the photon are siblings in this framework. Both are gapless excitations of the chiral vacuum. Both propagate at $v = c$. Both have exactly two polarisation states. The parallels are structural:

| **Property** | **Photon** | **Graviton** |
|---|---|---|
| Fundamental field | Complex scalar $D = \psi_L + i\psi_R$ | Complex scalar $\tau = \mathrm{Re}\,\tau + i\,\mathrm{Im}\,\tau$ |
| Target space | $\mathbb{C}$ (complex plane) | $\mathcal{H}$ (upper half-plane) |
| Symmetry protecting masslessness | $U(1)$ gauge invariance | $\mathrm{SL}(2,\mathbb{Z})$ modular invariance |
| Fundamental spin | 0 (complex scalar) | 0 (complex scalar) |

| Property | Photon | Graviton |
|---|---|---|
| Emergent spin in observable | 1 (one derivative in $F_{\mu\nu}$) | 2 (two derivatives in $h_{\mu\nu}$) |
| Polarisations (= real components) | Left-circular, right-circular | Shape ($h_+$), twist ($h_\times$) |
| Propagation speed | $v = c$ | $v = c$ |
| Classical waves detected | Yes (Maxwell, 1865) | Yes (LIGO, 2015) |
| Quantised theory | QED — renormalisable | $\tau$-field on $\mathcal{H}$ — constrained by $\mathrm{SL}(2,\mathbb{Z})$ |

The photon lives on the complex plane. The graviton lives on the upper half-plane. The complex plane is flat; the upper half-plane is curved (Poincaré metric). This is the geometric reason gravity is harder to quantise than electromagnetism — the target space has curvature — but it is a difference of degree, not of kind. Both are quantum fields. Both have well-defined Hilbert spaces. Both follow the same script.

The speed equality $v_{\text{photon}} = v_{\text{graviton}} = c$ is not a coincidence and not a postulate. Both excitations propagate through the same chiral vacuum, whose density sets $v = \mathcal{P}_v/\sqrt{\rho_{\text{vac}}}$. Change the vacuum, and both speeds change together. The speed of gravity equals the speed of light because there is only one medium.

## 15.9 The Graviton as the Photon's Shadow

The siblings table reveals something deeper than a parallel. The graviton is not merely *similar* to the photon — its source is driven by the photon's second-order projection.

The photon is a linear perturbation of the chiral field: $\delta D$. It carries phase, amplitude, and polarisation — the full wave information.

The graviton is a quadratic effect of the same field. The dilation field $\kappa$ responds to the intensity $|\psi_L|^2 - |\psi_R|^2$, and the metric is bilinear in $\tau$: $h_{\mu\nu} \sim \partial_\mu\tau\,\partial_\nu\bar{\tau}/(\mathrm{Im}\ \tau)^2$. The graviton carries what survives after phase is stripped — the intensity pattern projected onto the torus modular parameter. In optics, this projection is called a *shadow*.

This single identification explains every structural difference between the graviton and the photon:

| Property | Photon ($\boldsymbol{\delta D}$ — the wave) | Graviton ($\boldsymbol{\delta\tau}$ — driven by $\boldsymbol{\delta(|\psi_L|^2 - |\psi_R|^2)}$) |
|---|---|---|
| Order in the chiral field | First (linear) | Second (quadratic) |
| Phase information | Yes — full complex phase | Partial — phase angle stripped; amplitude sign ($\pm$) survives as valley/hill species |
| Spin | 1 (angular pattern of $\delta D$) | 2 (angular pattern of $|\delta D|^2$) |
| Coupling strength | $e$ (first-order) | $G$ (second-order — always weaker) |
| Polarisations | 2 (left/right circular) | 2 (Re and Im of the shadow) |

The spin doubling is the same phenomenon as in optics: the intensity pattern of a spin-$s$ wave carries angular dependence $2s$. A spin-1 photon casts a spin-2 shadow. The weakness of gravity follows immediately — a second-order effect is always smaller than the first-order signal it is derived from. The $10^{36}$ hierarchy between electromagnetism and gravity is not a fine-tuning problem. It is the generic suppression of a quadratic signal relative to a linear one, amplified by the vacuum stiffness $\mathcal{P}_v$.

The phase-stripping partially severs the thread between polarisation and source chirality — but only partially. Two distinct pieces of information are encoded in a gravitational wave, and the bilinear strips one while preserving the other.

The **polarisation angle** — whether the wave is $h_+$, $h_\times$, or some mix — carries no record of source chirality. A matter collapse and an antimatter collapse of the same geometry produce the same polarisation pattern. In this sense the two polarisation states are chirality-blind: both couple identically to matter and antimatter sources. This is what the shadow construction strips.

The **sign of the amplitude** — whether $\delta\kappa$ is positive or negative — is not stripped. It propagates from the source unchanged. A matter collapse ($\rho_L > \rho_R$) radiates $\delta\kappa < 0$: a deepening valley. A hypothetical antimatter collapse ($\rho_L < \rho_R$) would radiate $\delta\kappa > 0$: a growing hill. These are opposite signs of the same wave shape, and they are in principle distinguishable. Since all energy in the universe is chiral, every gravitational wave is signed — the bilinear construction determines the geometric form of the signal, but the sign of $\rho_L - \rho_R$ at the source writes itself into the amplitude and survives.

The $\tau$-field is independent — it has its own kinetic term, its own symmetry group, its own target space. What the shadow construction identifies is the **source coupling**: the signed intensity $|\psi_L|^2 - |\psi_R|^2$ of the chiral field drives $\delta\tau$ the same way a current drives a gauge field. The graviton is not made of photons. It is sourced by the same vacuum that photons propagate through, and the source term is quadratic in the photon field. Gravity is the second-order imprint that the chiral field leaves on the vacuum torus whenever its first-order oscillation **changes** the local signed intensity — it is the derivative $\delta(|\psi_L|^2 - |\psi_R|^2)$, not the level, that drives emission.

## 15.10 The Energy of a Graviton

The graviton is massless and obeys the same dispersion relation as the photon: $\omega = |\boldsymbol{k}|\, c$. A single graviton of frequency $f$ carries energy:

$$E = \hbar\omega = hf \tag{53}$$

In this framework the energy channel is two-component, because the underlying gravitational excitation is complex: $\delta\tau = \delta\tau_R + i\delta\tau_I$. The graviton energy can therefore be written in complex form:

$$\mathcal{E}_g = \hbar\Omega_g, \quad \Omega_g = \omega_R + i\omega_I, \tag{54}$$

so that

$$\mathcal{E}_g = E_R + iE_I, \quad E_R = \hbar\omega_R, \quad E_I = \hbar\omega_I. \tag{55}$$

The measurable scalar energy per quantum is the projection/modulus of this two-component energy, which reduces to the familiar one-line form $E = hf$ used above.

This is a prediction. The quantum of the $\tau$-field carries one quantum of energy set by $\hbar$, but with explicit real and imaginary components inherited from the complex gravitational degree of freedom.

**The graviton energy at LIGO.** The first gravitational wave event, GW150914, had a peak frequency of $f \approx 250$ Hz. A single graviton at this frequency carries:

$$E = hf = (6.626 \times 10^{-34}) \times 250 \approx 1.7 \times 10^{-31}\,\mathrm{J} \approx 1.0 \times 10^{-12}\,\mathrm{eV} \tag{56}$$

The $10^{-12}$ eV is a frequency statement only — a radio photon at 250 Hz carries the same energy. At equal frequency, a photon and a graviton carry identical $E = hf$; the Planck relation does not distinguish them. The weakness of the graviton is not in its energy formula. It lies in two compounding factors.

The first is the gravity-to-EM coupling ratio: $\alpha_G/\alpha_{\mathrm{EM}} = Gm_p^2/(\alpha_{\mathrm{EM}}\hbar c) \approx 10^{-36}$ — the familiar hierarchy between gravity and electromagnetism. The second comes from the shadow construction. The graviton source is not first-order in the photon field; it is the quadratic intensity $\delta(|\psi_L|^2 - |\psi_R|^2)$, so the coupling suppression enters twice. A graviton emitted by a single photon therefore carries a fraction of that photon's energy of order $(\alpha_G/\alpha_{\mathrm{EM}})^2 \approx (10^{-36})^2 = 10^{-72}$: roughly $10^{-72}$ eV for a visible-light photon, $10^{-72}$ times the source energy regardless of frequency. This is the energy per graviton quantum. The spherical wave that actually updates the vacuum nodes and drives gravitational acceleration $\vec{a} = -v^2\nabla(\delta\kappa)$ is not a single graviton — it is a coherent classical field built from $\sim 10^{36}$ gravitons emitted by the source photon. Their energies sum to $10^{36} \times 10^{-72} E_\gamma = 10^{-36} E_\gamma$: the total gravitational wave energy per source photon is suppressed by $10^{-36}$. The $10^{-36}$ is the classical gravitational field effect; the $10^{-72}$ is the energy carried by each individual quantum within it.

Two further observations follow naturally. First, a graviton of energy $10^{-72}$ eV has a de Broglie wavelength of order $hc/E \sim 10^{62}$ m — far larger than the observable universe ( $10^{26}$ m). Such a quantum cannot propagate as a free particle in any meaningful sense; it is better understood as a virtual mediator in the node-to-node handshake that carries the $\delta\kappa$ update through the vacuum network. Each node, upon receiving the update, re-emits it to its neighbours — a relay of near-field virtual gravitons rather than a single propagating free quantum.

Second, the photon does not lose energy in this process. The gravitons are sourced by the vacuum's chiral response to the photon's passage — the $\delta(|\psi_L|^2 - |\psi_R|^2)$ perturbation — not by the photon's own energy budget. The photon continues undisturbed; the gravitational wave is the vacuum's own re-organisation, paid for by the vacuum, not by the source. This is consistent with the equivalence principle: the photon's trajectory and energy are governed by the local $\kappa$-landscape, not by the gravitons it generates. Additionally, where the photon propagates all its energy in one direction, the graviton from a point source expands as a spherical wave (Section 15.5), distributing its effect simultaneously across every node of the outgoing shell — an additional geometric dilution that grows with distance. No detector can resolve individual gravitons from photon sources: the $10^{-72}$ coupling suppression and the spherical dilution together lie far beyond any foreseeable technology.

The GW150914 gravitons are a categorically different regime from the photon-sourced virtual quanta above. A merging black hole system — $\sim 60M_\odot$ of matter in violent acceleration — sources gravitons directly from a macroscopic chiral excess $\rho_L - \rho_R$, through the first-order coupling $G$, not the double-suppressed shadow channel. The result is gravitons with wavelength $\lambda = c/f \approx 1200$ km — far smaller than the $1.3 \times 10^9$ light-year travel distance — genuine free-propagating on-shell quanta. The event GW150914 radiated approximately $3M_\odot c^2 \approx 5.4 \times 10^{47}$ J. At $1.7 \times 10^{-31}$ J per graviton, this is roughly $3 \times 10^{78}$ quanta emitted in a fraction of a second. What LIGO measured was the classical wave — the expectation value $\langle \delta\tau \rangle$ — not individual quanta. The classical limit of $10^{78}$ gravitons is as classical as sunlight: real, measurable, and hiding its quantum granularity behind sheer number.

**The prediction.** A single graviton at frequency $f$ carries energy $E = hf$. This is identical in form to the photon, but the coupling is gravitational. The framework predicts that if a detector could ever resolve individual gravitons — at any frequency — their energy would obey this relation exactly. The graviton has no anomalous energy, no correction, no deviation from the Planck relation. It is as clean a quantum as the photon. The difference is not in the particle. It is in the weakness of the coupling that makes detection so difficult.

No collider can produce free (on-shell) gravitons at any detectable rate. The cross section for graviton production at the LHC scales as $Gs/(\hbar c^5) \sim 10^{-39}$ barn — thirty-three orders of magnitude below the strong interaction. Not one free graviton would be produced in the lifetime of any foreseeable accelerator. The cross section is suppressed by $G$ — and within this framework, the smallness of $G$ is itself a consequence of the vacuum stiffness $\mathcal{P}_v$: gravity is a second-order shadow of the chiral field, and the $10^{36}$ hierarchy between gravity and electromagnetism is the generic suppression of a quadratic signal relative to a linear one, amplified by $\mathcal{P}_v^2 \approx 4 \times 10^{130}$ Pa. The experimental challenge is sensitivity, not theory.

# 16 Predictions and Open Questions

This paper has not attempted to construct a full non-linear theory of gravity that reproduces general relativity in the strong-field regime. The objective was narrower and more specific: to identify the vacuum energy as the source of a quantum substrate whose properties — propagation speed and local dilation — give rise to flat spacetime and to weak-field gravity as a linear perturbation. All results in this paper concern the vacuum baseline and gentle ($\delta\kappa \ll 1$) departures from it. Non-linear extensions — the strong-field regime, black hole interiors, cosmological dynamics — are the subject of further work, not of this paper.

Within the scope of what has been established, the framework makes several predictions. Some are testable in principle; others are structural — they constrain the architecture of reality without yielding a near-term experiment.

## 16.1 Structural Predictions

### 16.1.1 The two layers of the speed of light

The Povazanec equation predicts that the speed of light has two independent sources of variation. The propagation speed $\upsilon = \mathcal{P}_v/\sqrt{\rho_L + \rho_R}$ responds to the *total* chiral energy density; the effective speed $c_{\text{eff}} = \upsilon \cdot \kappa$ responds additionally to the dilation field. All observed gravitational effects on light — Shapiro delay, gravitational redshift, lensing — are $\kappa$-effects. The $\upsilon$-correction from matter is of order $10^{-56}$ and beyond all foreseeable measurement. This is not a weakness of the theory. It is a prediction about the vacuum: the substrate is so stiff ($\mathcal{P}_v^2 \approx 4 \times 10^{130}$ Pa) that no concentration of matter in the observable universe measurably perturbs it.

### 16.1.2 The Scharnhorst effect

The equation predicts $\upsilon > c$ between Casimir plates — fewer vacuum modes, lower $\rho$, faster propagation. This reproduces the 1990 Scharnhorst–Barton QED result [2], [3] from one line, with the correct sign, scaling, and functional form. The magnitude ($\Delta\upsilon/c \sim 10^{-117}$ for micrometre plates) is unmeasurable, but the prediction is non-circular: the input (Casimir energy density) and the output (modified speed) are distinct quantities. Any future technology capable of measuring the Scharnhorst effect would constitute a direct test.

## 16.2 Testable Predictions

### 16.2.1 Source-side antimatter gravity

The framework predicts that antimatter, as a gravitational *source*, creates a repulsive field ($\kappa > 1$). This is distinct from the gravitational *response* of antimatter, which is attractive — confirmed by ALPHA-g [15]. No experiment has yet measured the gravitational field *produced by* a concentration of antimatter. A measurement of the gravitational field around a trapped antihydrogen cloud, or of the mutual gravitational interaction between matter and antimatter samples, would be decisive. The framework predicts repulsion; GR predicts attraction.

However, the universe itself may already be performing this experiment. The accelerating expansion of the universe — discovered in 1998 and attributed to dark energy — is precisely the large-scale signature one would expect if dispersed antimatter acts as a repulsive gravitational source. In the companion paper on Gravitational Polarity Symmetry [8], this connection is developed in detail: antimatter, gravitationally dispersed into the cosmic voids, provides a diffuse $\kappa > 1$ background that drives accelerating expansion without requiring a cosmological constant. The "laboratory experiment" may be the cosmos itself.

### 16.2.2 Baryon asymmetry as a gravitational selection effect

Matter ($\kappa < 1$) clumps gravitationally. Antimatter ($\kappa > 1$) disperses. In a universe that begins with equal chiral content, matter forms structures — galaxies, stars, observers — while antimatter thins into the voids. The observed baryon asymmetry is not a creation asymmetry but a *gravitational selection* asymmetry: we observe from within the clumped phase. No CP-violating baryogenesis mechanism is required. The universe has equal matter and antimatter — gravity simply sorts them.

This predicts that the cosmic void regions should carry a faint signature of diffuse antimatter — potentially detectable as anomalous gamma-ray emission from matter–antimatter annihilation at void boundaries.

### 16.2.3 Dark energy as a consequence of baryon separation

Dark energy follows directly from the baryon asymmetry. The antimatter that gravity dispersed into the voids does not vanish — it remains as a diffuse right-chiral energy distribution — in the form of antihydrogen atoms at a density of order one per cubic metre — with $\kappa > 1$ everywhere it resides. This *is* the dark energy. The framework identifies the accelerating expansion not as a cosmological constant $\Lambda$ and not as a new field, but as the gravitational back-reaction of the dispersed antimatter phase. The cause is the separation; the acceleration is its consequence.

This predicts that the dark energy equation of state is not exactly $w = -1$ — it carries the spatial signature of a dilute, void-filling field rather than a spacetime constant. It also predicts a correlation between the large-scale distribution of cosmic voids and the local dark energy density — a signature that future surveys may resolve. The full cosmological development of this picture — baryon separation, void antimatter, and accelerating expansion — is given in [8].

## 16.3 Open Questions

### 16.3.1 Non-linear $\kappa$

The weak-field equation $\nabla^2\kappa = g(\rho_L - \rho_R)$ is linear. Near a black hole, $\kappa \to 0$ and the linear approximation breaks down. The full non-linear extension — how $\kappa$ behaves when $\delta\kappa \sim 1$ — is the central open problem. The toroidal geometry suggests that the non-linear structure is encoded in the modular parameter $\tau$ on the upper half-plane, where the Poincaré metric provides a natural non-linear framework (the geodesic distance in $\mathcal{H}$ is logarithmic in Im $\tau$, which maps to $\ln\kappa$ — a hint that the non-linear variable is $\ln\kappa$, not $\kappa$ itself). This is left to future work.

### 16.3.2 Quantum $\kappa$: superposition of gravitational sources

The quantum gravity framework (Section 14) predicts that the dilation field can exist in superposition and exhibit entanglement. The twist–shape uncertainty relation $\Delta(\text{Re }\tau) \cdot \Delta(\text{Im }\tau) \geq 1/2$ implies a minimum gravitational uncertainty that could in principle be probed by interferometric experiments with massive particles in spatial superposition. The relevant mass scale is the Planck mass — far beyond current technology, but the prediction is precise.

### 16.3.3 Vacuum catalysis

Can the chiral balance of the vacuum be locally and deliberately broken? If so, one could in principle engineer a region of modified $\kappa$ — an engineered gravitational field. The Casimir effect already breaks the balance slightly (by excluding modes). Whether a stronger, controllable imbalance is physically possible is an open question with extraordinary implications.

# 17 Conclusion

The vacuum catastrophe is not a problem of calculation. It is a problem of routing. General relativity sends all energy — $10^{\{113\}}$ J/m³ of it — into the curvature channel and predicts a universe collapsed into a point. The universe is flat. Something is wrong with the routing.

This paper identifies the error and corrects it. The quantum vacuum has two chiral sectors, left and right, equal in magnitude and orthogonal in phase. Two independent combinations can be formed from them, and they do two different things:

- The sum $\rho_L + \rho_R$ sets the propagation speed of the vacuum through $v = \mathcal{P}_v/\sqrt{\rho_L + \rho_R}$. This is the Povazanec gravity equation. It gives the speed of light an origin — not as a fundamental constant, but as the response of an incomprehensibly stiff medium ($\mathcal{P}_v^2 \approx 4 \times 10^{130}$ Pa) to its own energy content.
- The difference $\rho_L - \rho_R$ produces spacetime curvature through $\nabla^2\kappa = g(\rho_L - \rho_R)$. This is the gravitational dilation field. For the vacuum, the difference is zero, and spacetime is flat. For matter, the difference equals the matter density, and Newtonian gravity — including weak-field general relativity — is recovered exactly.

The framework reproduces Maxwell's equations, the Dirac spectrum, the Klein–Gordon equation, Lorentz invariance, Newtonian gravity (the Poisson equation and the $g_{tt}$ component of the Schwarzschild metric), and the Scharnhorst effect. It does not modify general relativity in any experimentally tested Newtonian-limit regime. The full weak-field metric — including the spatial component $g_{rr}$ needed for light deflection and orbital precession — requires the non-linear extension of the $\tau$-field and is not derived in this paper. What the framework provides is the substrate from which that extension must be built: the vacuum energy as the source of flat spacetime, chiral imbalance as the source of curvature, and the torus modular parameter as the field that encodes both.

The underlying geometry is a two-radius torus $T^2$ at each spacetime point. The large radius carries the propagation speed; the small radius carries the dilation field. The torus modular parameter $\tau$ — a single complex number on the upper half-plane — encodes the complete gravitational state. In the $\tau$-plane, flat spacetime is a point, gravity is a displacement. The gravitational field, expressed as a $\tau$-field, is an ordinary quantum field — it can be superposed, entangled, and path-integrated by the standard rules. The conceptual barrier to quantum gravity dissolves: the flat background that perturbative QFT requires is not imposed from outside — it is the ground state that the chiral vacuum produces.

This reordering of priority — network first, geometry second — has a consequence that reaches beyond quantum gravity. In general relativity, the singularity is not a place where something dramatic happens to matter. It is a place where the mathematical description of spacetime itself breaks down: the equations stop, and physics ends. If spacetime is derivative, that breakdown is not fundamental — it is an artifact of mistaking the map for the territory. The network does not stop at a singularity. The torus deforms. The dilation field climbs. The modular parameter $\tau$ retreats to infinite geodesic distance in the upper half-plane, unreachable by any finite-energy process. The inside of a black hole is not where physics ends. It is where the description, built on the network rather than on the metric, remains valid throughout.

The deepest result is not in the list of what the framework reproduces. It is in what the framework did not need to impose. The torus has two radii, and those two radii are the two gravitational degrees of freedom — not matched to a pre-existing requirement, but identical to it. The modular group $\mathrm{SL}(2,\mathbb{Z})$ is the symmetry the torus already carries; it protects the graviton from acquiring a mass without any additional mechanism. The chiral sign that makes matter and antimatter gravitationally opposite is inherited from the Dirac equation's structure, not introduced by hand. The Poincaré metric that places the singularity at infinite geodesic distance is the unique Riemannian metric of the upper half-plane — it was already the natural kinetic term of the $\tau$-field before singularity resolution was ever identified as a target. Equal speeds of gravity and light need no coincidence argument: both are excitations of the same network, propagating through the same $v$. And the equation $d(d-3)/2 = 2$ has exactly one solution: $d = 4$. Spacetime has four dimensions because a complex scalar has two real degrees of freedom, and four is the only dimension in which the emergent metric requires exactly two polarisation states — no modes left over, none missing.

The substrate was chosen to resolve the vacuum energy routing problem. Gravity came along uninvited.

For quantum-field-theory readers, the key message is continuity of method with a shift of ontology: the standard machinery is unchanged, but the fundamental degrees of freedom are the substrate fields that generate geometry (see Section 14).

The framework makes one prediction that distinguishes it from general relativity and that the universe may already be testing: antimatter, as a gravitational *source*, is repulsive. Gravity sorts matter into clumps and antimatter into voids. The dispersed antimatter is the dark energy. The cause is the separation; the acceleration is its consequence.

General relativity is shown as the law of imbalance. This paper provides the substrate from which that imbalance is born: a chiral quantum vacuum whose two sectors, balanced, give flatness; and whose imbalance gives gravity and the shape of the universe.

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# APPENDIX A Nomenclature

The framework introduced in this paper — **Gravitational Polarity Symmetry** — is built on two named results:

- The **Povazanec gravity equation**: $v = \mathcal{P}_v/\sqrt{\rho_L + \rho_R}$, which gives the speed of light an origin as a property of the vacuum energy density. The $1/\sqrt{\rho}$ form is the universal scaling law of wave propagation in a medium.
- The **Povazanec constant** (also: Povazanec gravity constant): $\mathcal{P}_v = c^{9/2}/\left(\sqrt{\hbar} \cdot G\right) = (G \cdot \mathcal{P})^{1/5} \approx 2.04 \times 10^{65}\,\mathrm{kg}^{1/2} \cdot \mathrm{m}^{1/2} \cdot \mathrm{s}^{-2}$, the fundamental constant that couples total chiral energy density to propagation speed.

Together, these define the Gravitational Polarity Symmetry framework: Newton's constant $G$ governs how the chiral *difference* $(\rho_L - \rho_R)$ curves spacetime, and the Povazanec constant $\mathcal{P}_v$ governs how the chiral *sum* $(\rho_L + \rho_R)$ sets the speed of light. The speed of light $c = \mathcal{P}_v/\sqrt{\rho_{\mathrm{vac}}}$ is derived, not fundamental.