

# WORMHOLES HACK THE UNIVERSE

## A 3+1D GRAVITON-COMPUTING PROPOSAL

*Regular cores • Two mouths • Throat dynamics • Quantum channels*

**NICK RUGAI**

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**DIFFERENTIATE. RELATE. MEASURE.  
A0 IS THE PREMISE. THE MODEL IS THE TEST. REALITY HAS  
VETO POWER.**

*The ambition is epic. The evidential standard is not negotiable.*

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## Abstract and research status

The universe does not owe us a shortcut. A wormhole proposal earns scientific standing only when its geometry is regular, its field equations are stated, its source is physically admissible, its dynamics are stable, its causal structure is understood, and its observable consequences can be tested.

This manuscript rewrites the earlier wormhole framework entirely in 3+1-dimensional spacetime. It removes extra spatial dimensions, compactification, Kaluza–Klein transport, and any argument that equates the number of internal operators with the number of spatial directions. It integrates the proposed five-state graviton qdit and the Quantum Graviton Computing (QGC) framework, but it does not conflate a computational encoding with established graviton polarizations.

Three mathematical constructions are carried through far enough to become genuine benchmarks. First, the Hayward metric supplies a worked regular-black-hole core with finite central curvature. Second, a two-ended, horizonless wormhole is specified by smooth shape and redshift functions and matched to Schwarzschild exteriors at two finite mouth surfaces. Its effective stress tensor is calculated from Einstein’s equations, including the exact null-energy requirement at the throat. Third, a five-state input-output channel is defined with unitary and noisy limits, explicit operators, a curvature-sensitive transition Hamiltonian, and a fidelity benchmark.

These are not three pieces of one already-derived solution. The Hayward core is not, by itself, a wormhole. The two-mouth metric is an exact geometry-first solution supported by the effective stress tensor it requires, but the manuscript does not yet derive that stress tensor from the qdit action. The qdit channel is mathematically well-defined, but it is not evidence that a physical wormhole exists. The central open problem is to derive the metric, support, and transport from one covariant microscopic model without tuning the desired answer into the equations.

The research stance is therefore ambitious but conditional: build the best explicit 3+1D candidate, expose every necessary condition, and let calculation and observation decide. No hidden dimensions are required to state the problem. No claim of a solved physical portal is made.

## Reading key: evidence labels

| Label       | Meaning                                                              | How it is used here                                                                                                                   |
|-------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| ESTABLISHED | Standard mathematical or empirical background.                       | General relativity, stress-energy conservation, quantum-channel mathematics, and the observed 3+1D large-scale spacetime description. |
| DERIVED     | Follows from an explicitly stated equation or construction.          | The Hayward central expansion; throat flare-out relation; mouth-matching conditions; qdit channel fidelity.                           |
| BENCHMARK   | An exact mathematical reference model, not a claim about nature.     | The smooth two-mouth geometry and its required effective source.                                                                      |
| ANSATZ      | A proposed action, coupling, or parameterization chosen for testing. | Qdit curvature mixing and scalar–Gauss–Bonnet dynamics.                                                                               |
| CONJECTURE  | A TOE interpretation not yet derived or experimentally established.  | The claim that five-state gravitational computation underlies wormhole formation.                                                     |
| OPEN        | A missing derivation or test.                                        | Whether qdit dynamics can support the required throat, remain stable, and produce distinctive observables.                            |

## The executive verdict

A useful solution has been obtained at the geometric level: a regular, two-ended, static, horizonless bridge can be written in 3+1D and smoothly matched to two Schwarzschild exteriors. Its required effective radial null-energy violation is explicit. A separate regular-core black-hole metric is also available as a central benchmark. The manuscript’s biggest remaining gap is no longer “what might a wormhole look like?” It is: “Can the proposed five-state qdit and its covariant action produce this source and this geometry, with acceptable stability and observables?”

# 1. The evidential contract and the central claim

The phrase “hack the universe” is the title’s energy, not a license to bypass its laws. A physical shortcut is a global spacetime construction; it is not a local particle outrunning light. A wormhole is a geometry with a throat connecting regions that would otherwise be separated. Traversability adds much stronger requirements: no horizon may block the intended route, tidal forces must be tolerable for the specified payload, support must persist under perturbations, and the full causal structure must be acceptable [1–5].

The working TOE premise A0 is “ALL IS EPISTEMIC.” In this manuscript A0 is treated as the philosophical premise of the research program, not as a theorem of general relativity. Every subsequent physical statement is classified independently. Standard geometry can constrain a speculative interpretation without validating its ontology. Conversely, a compelling interpretation cannot replace a missing field equation.

The central hypothesis is that a five-state gravitational computational sector may participate in the relationship between matter, curvature, and spacetime connectivity. That proposal is worth formalizing only if it can recover ordinary gravity in the appropriate regime, specify its degrees of freedom, generate a stress tensor or modified metric equation, and make a quantitative prediction not already contained in the chosen benchmark metric.

## What this manuscript will and will not claim

- It will give exact reference geometries for a finite-curvature black-hole center and a smooth two-mouth traversable bridge.
- It will derive the throat’s required null-energy condition and expose the amount of effective violation in the benchmark.
- It will define the qdit state space, projectors, transition dynamics, covariant effective-action candidate, and open quantum channel.
- It will show precisely where a curvature-only diagonal coupling fails to transfer occupation into the proposed hidden subspace.
- It will not claim that the qdit is an observed property of gravitons, that a scalar–Gauss–Bonnet action uniquely follows from QGC, or that the benchmark wormhole is an astrophysical object.
- It will not call an inverse-engineered metric a first-principles solution. The source it requires must still be derived from the proposed dynamics.

A theory that survives this audit gets stronger, not weaker. The purpose of a clean boundary between result and conjecture is to make progress cumulative instead of rhetorical.

## 2. Four-dimensional arena: geometry is not Hilbert-space dimension

The model is formulated on a four-dimensional Lorentzian manifold with one time coordinate and three spatial coordinates. We use signature  $(-,+,+,+)$ , and set  $G=c=\hbar=1$  unless dimensions are restored explicitly. Nothing in a five-dimensional complex Hilbert space adds a fifth spatial direction to this manifold.

$$\mathcal{H}g = \mathbb{C}^5; \quad \rho = \rho^\dagger, \quad \rho \geq 0, \quad \text{Tr } \rho = 1. \quad (2.1)$$

A five-level register has 25 real degrees of freedom in its Hermitian operator space. Fixing the trace removes one independent real component, leaving 24 coordinates for a trace-one Hermitian state. With traceless Hermitian generators  $T_A$  normalized by  $\text{Tr}(T_A T_B) = \delta_{AB}/2$ , write

$$\rho = I_5/5 + \Sigma(A=1\dots 24) q_A T_A. \quad (2.2)$$

The coefficients  $q_A$  are constrained by positivity of  $\rho$ . They are not automatically 24 propagating fields, 24 forces, or 24 compact directions. A field theory must separately state which components vary in spacetime, how the constraints are maintained, and what action controls their dynamics.

### Three “five-state” notions must remain distinct

| Object                        | Correct statement                                                                                                                       | What it does not prove                                                                            |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Massless spin-2 in 3+1D       | Two radiative helicities in the usual low-energy description of GR.                                                                     | It does not provide five physical massless polarizations.                                         |
| Massive spin-2 representation | A conventional Lorentz-invariant massive spin-2 field carries five physical polarization states when healthy constraints are satisfied. | The number five does not show that the ordinary graviton is massive or that QGC is realized.      |
| Five-state graviton qdit      | A proposed five-level computational encoding associated with a gravitational sector.                                                    | It is not automatically either particle representation above; the correspondence must be derived. |

For the proposed encoding, let  $|1\rangle$  and  $|2\rangle$  denote the states intended to support the familiar classical helicity projection, while  $|3\rangle$ ,  $|4\rangle$ , and  $|5\rangle$  denote additional computational states. This is a basis convention for the hypothesis, not an empirical identification.

$$P_2 = |1\rangle\langle 1| + |2\rangle\langle 2|, \quad P_3 = \Sigma(b=3\dots 5) |b\rangle\langle b|. \quad (2.3)$$

$$P_2 + P_3 = I_5, \quad P_2 P_3 = 0, \quad P_i^2 = P_i. \quad (2.4)$$

$$s = \text{Tr}(\rho P_3), \quad 0 \leq s \leq 1. \quad (2.5)$$

The scalar  $s$  is an operationally clear occupation statistic. It does not encode all 24 coordinates, and it cannot replace the density matrix when coherences matter. The projectors separate the proposed classical-projection sector from the remaining register subspace without introducing extra spatial dimensions.

### 3. What classical general relativity says about black-hole centers

A Schwarzschild black hole has exterior line element

$$ds^2 = -(1 - 2M/r)dt^2 + dr^2/(1 - 2M/r) + r^2d\Omega^2. \quad (3.1)$$

$$K \equiv R_{\mu\nu\rho\sigma}R_{\mu\nu\rho\sigma} = 48 M^2/r^6. \quad (3.2)$$

The surface  $r=2M$  is a coordinate singularity in these coordinates; the curvature invariant remains finite there. At  $r=0$  the Kretschmann invariant diverges. The central singularity is a failure of the classical solution as a complete physical description, not a demonstrated hole in a literal fabric and not evidence that a higher spatial dimension must exist.

The Einstein–Rosen bridge in the maximally extended eternal Schwarzschild solution is not a traversable tunnel. Its causal structure prevents a traveler from entering one exterior and emerging into the other. A black-hole event horizon is a global causal boundary: once a future-directed causal path crosses into the trapped region, classical outward travel to that same exterior is not available. Any proposal that treats observed black holes as two-way doors must replace or modify this causal structure and show how the replacement agrees with external observations.

#### What is the “center” in each model?

| Geometry           | Central object                                      | Correct interpretation                                                                                |
|--------------------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Schwarzschild      | Curvature-singular $r=0$ in the classical solution. | Reference failure of classical GR at the center; not a traversable wormhole solution.                 |
| Regular black hole | A finite-curvature core at $r=0$ .                  | The origin remains part of the geometry; finite curvature alone does not connect to another exterior. |
| Two-ended wormhole | A minimum-area throat at $r=r_0$ in areal radius.   | There is no ordinary $r=0$ center on the bridge. The throat connects two exterior regions.            |

This distinction is foundational. A regular center and a wormhole throat are different boundary conditions. One may construct hybrid scenarios in modified gravity, but the transition from one to the other must follow from a single solution, not from changing the name of the coordinate origin.

## 4. Worked regular-center benchmark: the Hayward geometry

To ask whether a gravitational-state field can regularize a center, first choose a transparent target geometry whose regularity can be checked independently. The Hayward metric is a useful benchmark [6]:

$$ds^2 = -f(r)dt^2 + dr^2/f(r) + r^2d\Omega^2, \quad f(r) = 1 - 2Mr^2/(r^3 + 2M\ell^2). \quad (4.1)$$

$$m(r) = Mr^3/(r^3 + 2M\ell^2), \quad f(r) = 1 - 2m(r)/r. \quad (4.2)$$

Here  $M$  is the asymptotic mass parameter and  $\ell$  is a core scale. In geometrized units,  $M$  and  $\ell$  have dimensions of length. The model is asymptotically Schwarzschild because  $f(r) = 1 - 2M/r + O(r^{-4})$  at large  $r$ .

### Central expansion

$$r \rightarrow 0: \quad m(r) = r^3/(2\ell^2) + O(r^6), \quad f(r) = 1 - r^2/\ell^2 + O(r^5). \quad (4.3)$$

$$R(0) = 12/\ell^2, \quad K(0) = 24/\ell^4, \quad \mathcal{G}(0) = 24/\ell^4. \quad (4.4)$$

The center is de Sitter-like at leading order. Both the Ricci scalar  $R$  and Kretschmann scalar  $K$  remain finite, as does the Gauss–Bonnet invariant  $\mathcal{G}$ . The finite values are set by  $\ell$ ; a smaller core scale produces larger but still finite curvature. Regularity is therefore an explicit mathematical statement, not an adjective.

### Effective source required by Einstein's equations

If the metric is interpreted within ordinary Einstein gravity, the stress tensor is the one required by  $G_{\mu\nu} = 8\pi T_{\mu\nu}$ . Its principal components are

$$\rho(r) = 3M^2\ell^2 / [2\pi(r^3 + 2M\ell^2)^2], \quad p_r(r) = -\rho(r). \quad (4.5)$$

$$p_t(r) = 3M^2\ell^2(r^3 - M\ell^2) / [\pi(r^3 + 2M\ell^2)^3]. \quad (4.6)$$

$$\rho(0) = 3/(8\pi\ell^2), \quad p_r(0) = p_t(0) = -\rho(0). \quad (4.7)$$

At the center the source is locally vacuum-like: equal negative pressures and positive finite energy density. Away from the center it is anisotropic. These expressions define the effective source needed for this geometry. They do not establish that ordinary matter, the I-field, or the qdit supplies it.

### Horizon test

$$f(r) = 0 \Leftrightarrow r^3 - 2Mr^2 + 2M\ell^2 = 0. \quad (4.8)$$

The critical merger of the two positive horizons occurs at  $r = 4M/3$  and  $\ell = 4M/(3\sqrt{3})$ . For  $0 < \ell < 4M/(3\sqrt{3})$ , the benchmark has two positive horizons; at the critical value they merge; for larger  $\ell$  there is no positive horizon in this family. A horizon-bearing regular black hole and a horizonless compact object therefore occupy different parameter regimes.

The result answers one part of the central question: a finite-curvature core is mathematically possible in a 3+1D metric. It does not answer whether that core is connected to a second exterior, whether its inner structure is stable under collapse, or whether the qdit produces the required source. No extra spatial dimension appears in the construction.

## 5. Two mouths and one throat: the exact geometric conditions

A static, spherically symmetric, two-ended wormhole can be described in Morris–Thorne form [1]:

$$ds^2 = -e^{2\Phi(r)}dt^2 + dr^2/[1-b(r)/r] + r^2d\Omega^2. \quad (5.1)$$

The redshift function  $\Phi(r)$  controls the lapse; the shape function  $b(r)$  controls the spatial geometry. A throat at  $r=r_0$  requires  $b(r_0)=r_0$ . A traversable static throat also requires  $e^{2\Phi(r)}>0$  and finite throughout the route. The flare-out condition is  $b'(r_0)<1$ . For an asymptotically flat exterior,  $b(r)/r \rightarrow 0$  and  $\Phi(r) \rightarrow 0$  in a time coordinate normalized at infinity.

$$b(r_0)=r_0, \quad b'(r_0)<1, \quad e^{2\Phi(r)}>0. \quad (5.2)$$

The coordinate coefficient  $g_{rr}$  diverges at  $r=r_0$  in (5.1), but that does not by itself indicate a curvature singularity. Introduce signed proper radial distance  $l$ :

$$dl/dr = \pm[1-b(r)/r]^{-1/2}, \quad dr/dl = \pm\sqrt{1-b(r)/r}. \quad (5.3)$$

The two signs cover the two sides of the throat. A smooth reflection-symmetric bridge is described by  $r(l)=r(-l)$ , with  $r(0)=r_0$  and  $dr/dl=0$  at  $l=0$ . The throat is the minimum area sphere, with area  $A_0=4\pi r_0^2$ . The two mouths are finite transition regions where the wormhole interior joins external spacetime, not additional spatial dimensions.

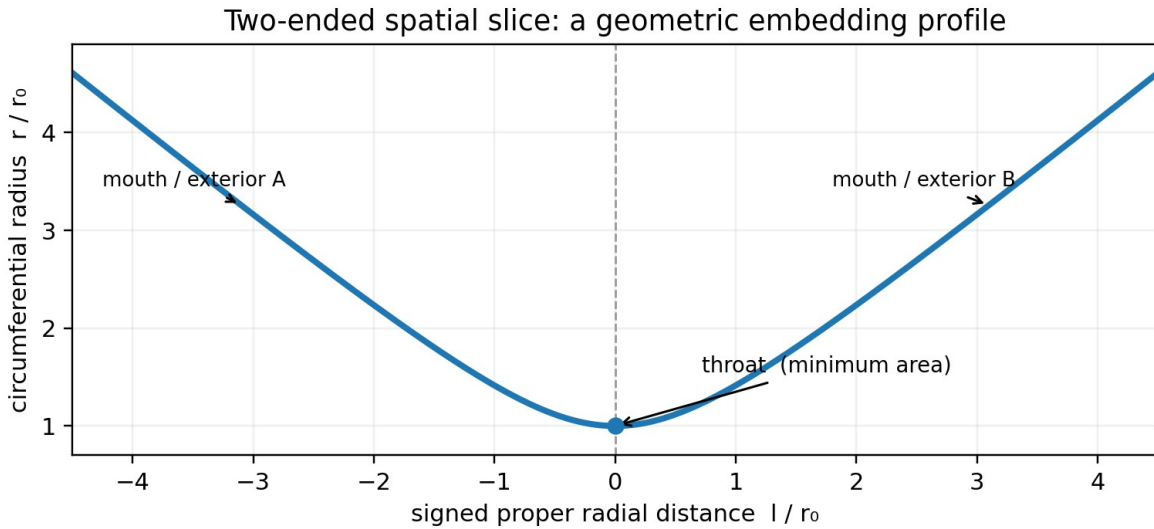


Figure 1. For the analytic profile  $r(l)=\sqrt{r_0^2+l^2}$ , the signed proper distance passes smoothly through a minimum-area throat. The embedding plot is a geometric visualization of a spatial slice, not a claim of an extra physical spatial dimension.

### The throat's null-energy ledger

In ordinary four-dimensional Einstein gravity, the field equations at a static throat imply

$$\rho + p_r = [b'(r_0)-1]/(8\pi r_0^2) < 0. \quad (5.4)$$

This is the radial null-energy-condition (NEC) violation required by the flare-out geometry [1–4]. It is not a matter of terminology. For a radial null vector  $k_\mu$ , the contraction  $T_{\mu\nu}k_\mu k_\nu$  is proportional to  $\rho+p_r$  in the orthonormal frame. If Einstein's equations are used with an effective source, that effective source must violate the NEC at the throat. In a modified-gravity description, one may move curvature terms to the right-hand side, but the bookkeeping must then identify what violates the effective condition and why the full theory remains stable.

The Raychaudhuri equation makes the geometric tension visible. For a hypersurface-orthogonal null congruence with affine parameter  $\lambda$ , expansion  $\theta$ , and shear  $\sigma_{\mu\nu}$ ,

$$d\theta/d\lambda = -\theta^2/2 - \sigma_{\mu\nu}\sigma^{\mu\nu} - R_{\mu\nu}k_\mu k_\nu. \quad (5.5)$$

A flare-out requires defocusing rather than the focusing expected from positive null convergence. Under Einstein's equations, this requires negative null stress in the relevant regime. A slogan such as “the qdit opens the fabric” must therefore cash out as a term in the field equations that changes this calculation.

## 6. Worked two-mouth solution matched to Schwarzschild exteriors

This chapter supplies an explicit geometry-first construction. It is an exact benchmark for mouth, throat, and travel-time calculations. It is not yet derived from the qdit action. The geometry is chosen first, and its required stress tensor follows from Einstein's equations. That distinction is the whole point: the benchmark tells us exactly what a microscopic model must reproduce.

### 6.1 Exterior and matching radius

Let  $M > 0$  be the asymptotic mass parameter and choose a throat radius  $0 < r_0 < 2M$ . Select a mouth matching radius  $r_m > 2M$  and define  $\Delta = r_m - r_0$ ,  $x = (r - r_0)/\Delta$ . Use a smooth quintic step

$$S_5(x) = 6x^5 - 15x^4 + 10x^3, \quad 0 \leq x \leq 1. \quad (6.1)$$

It obeys  $S_5(0) = 0$ ,  $S_5(1) = 1$ ,  $S_5'(0) = S_5'(1) = 0$ , and  $S_5''(0) = S_5''(1) = 0$ . Define the interior shape function

$$b(r) = r_0 + (2M - r_0)S_5(x), \quad r_0 \leq r \leq r_m. \quad (6.2)$$

For  $r \geq r_m$ , take  $b(r) = 2M$ . Then  $b$  and its first two  $r$ -derivatives match the Schwarzschild exterior at the mouth. The interior condition  $b(r) < r$  is guaranteed by the conservative sufficient bound

$$\Delta \geq (5/4)(2M - r_0), \quad \text{with } r_m > 2M. \quad (6.3)$$

The factor  $5/4$  safely exceeds  $\max[S_5(x)/x] \approx 1.198$  on  $0 < x \leq 1$ . The inequality is sufficient rather than necessary; it is chosen to make the no-horizon check transparent. It ensures  $b(r) < r$  for every  $r$  strictly above the throat, so  $1 - b/r$  stays positive away from  $r_0$ .

### 6.2 Redshift function with smooth Schwarzschild matching

The exterior redshift function is

$$\Phi_{\text{ext}}(r) = \frac{1}{2} \ln(1 - 2M/r), \quad r \geq r_m. \quad (6.4)$$

At  $r_m$ , define the dimensionless derivatives

$$d = \Delta \Phi'_{\text{ext}}(r_m) = \Delta M / [r_m(r_m - 2M)], \quad e = \Delta^2 \Phi''_{\text{ext}}(r_m). \quad (6.5)$$

$$\Phi''_{\text{ext}}(r) = -2M(r - M) / [r^2(r - 2M)^2]. \quad (6.6)$$

Let  $\Phi_m = \Phi_{\text{ext}}(r_m)$ , and on the interior define

$$\Phi(r) = \Phi_m + (e/2 - 4d)x^3 + (7d - e)x^4 + (e/2 - 3d)x^5. \quad (6.7)$$

By construction,  $\Phi$ ,  $\Phi'$ , and  $\Phi''$  match their Schwarzschild exterior values at  $r_m$ . At the throat  $x = 0$ ,  $\Phi$  is finite and its first two  $x$ -derivatives vanish; reflection across the throat gives a smooth even profile in proper radial distance. Because  $\Phi$  is finite,  $e^{2\Phi}$  remains positive: there is no horizon in the interior. The external Schwarzschild region is only used for  $r \geq r_m > 2M$ , so the exterior also contains no horizon on the matched spacetime.

### 6.3 Global two-ended metric

$$ds^2 = -e^{2\Phi(r(l))} dt^2 + dl^2 + r^2(l) d\Omega^2, \quad -\infty < l < \infty. \quad (6.8)$$

The signed coordinate  $l$  is obtained by integrating (5.3);  $r(l)$  decreases from the left exterior to  $r_0$  and increases toward the right exterior. Reflection-symmetric copies of the interior join at  $r(0) = r_0$ , and both ends approach Schwarzschild with mass  $M$ . The matching surfaces carry no thin shell: the induced metric and extrinsic curvature are continuous. Because  $b$  and  $\Phi$  match through second derivatives, the Einstein tensor—and the effective source defined from it—joins continuously to the vacuum source at each mouth.

### 6.4 Exact source implied by the metric

In units  $G = c = 1$ , the Einstein equations give the following orthonormal stress components for the metric (5.1):

$$\rho(r)=b'/(8\pi r^2). \quad (6.9)$$

$$p_r(r)=[-b/r^3+2(1-b/r)\Phi'/r]/(8\pi). \quad (6.10)$$

$$p_t(r)=(1-b/r)/(8\pi) \times [\Phi''+(\Phi')^2+\Phi'/r \\ -((b'r-b)/(2r(r-b)))\Phi'-(b'r-b)/(2r^2(r-b))]. \quad (6.11)$$

These formulas are the required effective source: set  $T_{\mu\nu,eff}=G_{\mu\nu}/(8\pi)$ . The geometry therefore solves the Einstein equations exactly for that anisotropic source. No additional source model has yet been supplied. At the throat, because  $b(r_0)=r_0$  and  $b'(r_0)=0$ , the limiting values simplify to

$$\rho(r_0)=0, \quad p_r(r_0)=-1/(8\pi r_0^2), \quad \rho+p_r=-1/(8\pi r_0^2)<0. \quad (6.12)$$

$$p_t(r_0)=1/(16\pi r_0^2), \quad \text{for the constructed profile with } \Phi'(r_0)=0. \quad (6.13)$$

The limiting transverse pressure in (6.13) follows from (6.11), not from substituting  $r=r_0$  into terms that separately look singular. The throat therefore has zero energy density, negative radial pressure, and positive transverse pressure in this benchmark. The radial NEC violation is exact and is the requirement the qdit-plus-field model must reproduce. Away from the throat, (6.9)–(6.11) give the complete effective source for any admissible  $M$ ,  $r_0$ , and  $r_m$ .

### 6.5 A reproducible dimensionless example

Choose  $M=1$ ,  $r_0=1$ , and  $r_m=2.5$  in geometrized units. Then  $\Delta=1.5$ , while  $(5/4)(2M-r_0)=1.25$ , so the sufficient inequality is satisfied. The exterior lapse at the mouth is  $e^2\Phi_m=1-2M/r_m=0.2$ . The constructed interior has a minimum lapse  $e^2\Phi\approx 0.108$ , still strictly positive. Numerical quadrature gives a one-sided proper radial distance from throat to mouth of approximately 4.340  $M$  and a one-sided radial null coordinate travel time of approximately 11.341  $M$ . The full mouth-to-mouth null travel time in the normalized static time coordinate is approximately 22.683  $M$ .

These numbers are geometric diagnostics, not astrophysical predictions. They follow from the chosen benchmark functions and parameter values. They do not show that QGC supplies the required stress tensor, nor do they establish stability under perturbations. The calculation is reproducible from equations (6.1)–(6.7) without invoking additional dimensions.

### 6.6 What this solution proves—and what it does not

| Question                                                | Result                                                                                             | Status                         |
|---------------------------------------------------------|----------------------------------------------------------------------------------------------------|--------------------------------|
| Can 3+1D geometry have two mouths and a regular throat? | Yes; the explicit metric meets the stated geometric and matching conditions.                       | Derived benchmark.             |
| Is the benchmark traversable at the metric level?       | Yes; the lapse is finite and nonzero along the route, and proper distance is regular.              | Geometric criterion satisfied. |
| What supports the throat in Einstein gravity?           | The anisotropic effective stress tensor in (6.9)–(6.11); $\rho+p_r<0$ at the throat.               | Exact source requirement.      |
| Has the qdit action been shown to generate this source? | No.                                                                                                | Open derivation.               |
| Has stability been proven?                              | No. Background regularity does not determine the perturbation spectrum.                            | Open test.                     |
| Is this an astrophysical black hole?                    | No. It is horizonless and therefore is not a black hole under the strict event-horizon definition. | Important distinction.         |

## 7. What the throat must be made of: the null-energy ledger

The geometry-first solution removes ambiguity about the support problem. Its effective source must satisfy the Einstein equations component by component. At the throat,  $\rho + p_r$  is negative, and the source must maintain that condition under perturbations if the throat is to remain open. The same requirement is generic for static traversable throats in Einstein gravity [1–4].

There are two logically different ways to continue. In an ordinary-GR description, the proposed matter/field sector must generate the necessary negative null stress. In a modified-gravity description, additional curvature terms can change the metric equations, so the geometric side need not be equivalent to a conventional matter tensor alone. But the theory must still be rewritten consistently, its effective stress defined transparently, and its dynamical degrees of freedom tested for instability. Moving a term across the equality sign does not make the physical burden vanish.

### Why an ordinary canonical scalar is not enough

For a minimally coupled scalar with  $L = -\frac{1}{2}(\nabla\phi)^2 - V(\phi)$ , its null contraction is

$$T_{\mu\nu}(\phi) k^\mu k^\nu = (k^\mu \nabla_\mu \phi)^2 \geq 0 \quad \text{for every null } k^\mu. \quad (7.1)$$

The potential term drops out because  $g_{\mu\nu} k^\mu k^\nu = 0$ . A canonical scalar alone therefore obeys the NEC and does not supply the negative radial null stress needed by a static traversable throat in ordinary Einstein gravity. A positive-energy I-field, a generic quantum register, or a stable dark-matter population cannot be assumed to support a wormhole merely because it is novel.

Nonminimal curvature couplings can change the effective field equations and may allow geometries not supported by the canonical scalar alone. That is why the scalar–Gauss–Bonnet candidate is worth testing. It is not why it should be assumed to succeed. Existence, regularity, perturbative stability, effective-field-theory control, and causal propagation remain separate gates [7,8].

## 8. Matter entering both mouths: flux, collision, and backreaction

The two-ended geometry specifies possible trajectories, not the dynamics of continuously fed matter. A static benchmark is time-independent and diagonal; two inward streams generally add flux and counter-streaming stress, forcing evolution unless interactions and energy balance support stationarity.

The correct conservation law is covariant conservation of the total source implied by the full diffeomorphism-invariant action:

$$\nabla_\mu T_{\mu\nu,\text{total}} = 0. \quad (8.1)$$

If ordinary matter and the qdit-associated sector exchange energy or momentum, their separate stress tensors need not be conserved individually. Introduce an exchange current  $J_\nu$  and require the terms to cancel:

$$\nabla_\mu T_{\mu\nu,\text{matter}} = J_\nu, \quad \nabla_\mu T_{\mu\nu,\text{qdit+other}} = -J_\nu. \quad (8.2)$$

This relation is a bookkeeping requirement, not a microphysical law for  $J_\nu$ . The actual exchange current must be derived from the couplings. It determines whether incident matter is transmitted, reflected, absorbed into a long-lived throat mode, converted into radiation, or increases the mass/curvature of the bridge.

A local orthonormal-frame calculation makes one important limit explicit. Model two narrow, radial, positive-energy null streams by

$$T_{\text{stream}} = \varepsilon_+(k_+ \otimes k_+) + \varepsilon_-(k_- \otimes k_-), \quad k_\pm = (1, \pm 1, 0, 0). \quad (8.3)$$

For balanced streams  $\varepsilon_+ = \varepsilon_- = \varepsilon$ , the net radial energy flux cancels,  $T^{0r} = 0$ , but energy density and radial pressure do not:

$$T^{00} = T^{rr} = 2\varepsilon, \quad T^{0r} = 0, \quad T(n, n) = \Sigma \pm \varepsilon_\pm (k_\pm \cdot n)^2 \geq 0. \quad (8.4)$$

Therefore, counter-streaming ordinary null matter can remove net momentum flux at a symmetry surface, but it does not supply the negative null stress required by a traversable throat in Einstein gravity. Its positive energy still gravitates and can drive collapse or destabilize the background. The throat-support mechanism must be a separate derived contribution.

### The two-inflow problem

- Stationary balanced flux: possible only if the total radial energy flux and momentum exchange satisfy the static field equations everywhere, not merely at the symmetry surface.
- Counter-streaming collision: both streams contribute to local energy density and pressure even if their net momentum flux cancels at one point. The stress can increase central curvature and destabilize an otherwise regular background.
- Asymmetric feeding: the two mouths accumulate different energies; the throat geometry and redshift functions become time dependent, and a static transmission operator is no longer adequate.
- Horizon-bearing mouths: if either mouth is a true classical black-hole exterior with an event horizon on the route, ordinary outbound transit is causally blocked. A traversable model must say exactly how its causal structure differs.

For a static observer,  $E_\infty = e^{\Phi(r)} E_{\text{local}}$ . An ideal lossless signal between static mouths has  $E_{\text{local},B}/E_{\text{local},A} = e^{\Phi(A) - \Phi(B)}$ ; equal mouths cancel net endpoint redshift, though intermediate energies and tides vary. Moving mouths add Doppler and synchronization effects.

## 9. The five-state graviton qdit: operators, projectors, and transitions

The proposed five-state qdit is a finite-dimensional computational system associated with the gravitational sector. It is not inserted as an additional physical polarization of a massless graviton. The classical low-energy projection is supposed to recover the observed two-helicity behavior; the remaining internal-state structure is a conjecture that must be given operational meaning.

### State representation and occupation

$$\rho_g \in \mathbb{C}^{5 \times 5}, \quad \rho_g = \rho_g^\dagger, \quad \rho_g \geq 0, \quad \text{Tr } \rho_g = 1. \quad (9.1)$$

$$\rho_g = I_5/5 + \sum_{A=1 \dots 24} q_A T_A, \quad \text{Tr}(T_A T_B) = \delta_{AB}/2. \quad (9.2)$$

$$s = \text{Tr}(\rho_g P_3), \quad 0 \leq s \leq 1. \quad (9.3)$$

The 24 traceless Hermitian generators are the natural coordinates of the trace-one operator space. Their count is algebraic. A microscopic theory must decide whether any  $q_A$  are fields, constraints, gauge redundancies, virtual components, or operationally inaccessible coordinates.

### A curvature term alone may not activate the additional states

Let the closed-register state evolve in proper time  $\tau$  as

$$d\rho_g/d\tau = -i[H(\tau), \rho_g]. \quad (9.4)$$

Then the occupation statistic obeys

$$ds/d\tau = i \text{Tr}(\rho_g [H, P_3]). \quad (9.5)$$

If  $H$  commutes with  $P_3$ , then  $ds/d\tau = 0$ . A Hamiltonian proportional only to  $R P_3$  or  $\mathcal{G} P_3$  changes relative phases between subspaces but does not move occupation between them. This is a precise failure mode for a naive “curvature switches on hidden states” story. Activation requires off-diagonal couplings between the  $P_2$  and  $P_3$  sectors, or another explicitly noncommuting process.

### A testable curvature-mixing ansatz

One candidate proper-time Hamiltonian is

$$H(\tau) = H_0 + [R(\tau)/\Lambda] Q_R + [\mathcal{G}(\tau)/\Lambda^3] Q_G + H_{\text{mix}}(\tau). \quad (9.6)$$

Here  $\Lambda$  is an energy scale,  $Q_R$  and  $Q_G$  are dimensionless Hermitian operators, and  $H_{\text{mix}}$  contains off-diagonal terms such as

$$H_{\text{mix}} = \sum_{(a=1 \dots 2, b=3 \dots 5)} [\kappa_{ab}(\tau) |a\rangle\langle b| + \kappa_{ab}^*(\tau) |b\rangle\langle a|]. \quad (9.7)$$

The coefficients  $\kappa_{ab}$  have dimensions of energy and must be specified by a covariant interaction model; they are not known constants of nature. In a weak-mixing regime, a transition amplitude is

$$A(b \leftarrow a) \approx -i \int d\tau \langle b | H_{\text{mix}}(\tau) | a \rangle, \quad P(a \rightarrow b) \approx |A(b \leftarrow a)|^2. \quad (9.8)$$

This is an operational calculation path: a chosen background gives  $R(\tau)$  and  $\mathcal{G}(\tau)$ , a specified coupling determines  $H_{\text{mix}}$ , and the resulting transition probabilities can be computed. Until  $\kappa_{ab}$  and  $\Lambda$  are derived or constrained, the result is a parameterized model, not a prediction. Curvature may drive state evolution; the reverse question—whether those states materially change curvature—requires the field action and its stress tensor.

## 10. From qdit dynamics to a covariant field theory

A trajectory-level finite-dimensional Hamiltonian cannot source spacetime geometry by itself. The qdit needs a local field-theoretic layer, symmetry rules, a classical limit, and a metric variation that yields a consistent source.

### 10.1 Matrix-valued effective action candidate

A minimal 3+1D ansatz, intended as a starting point for variation rather than as established physics, is

$$S = \int d^4x \sqrt{-g} \{ \frac{1}{2} F(s) R - f^2/4 \text{Tr}(\nabla_\mu \rho \nabla_\mu \rho) - V(\rho) + \alpha h(s) \mathcal{G} + \mathcal{L}_m \}, \quad F(s) = M_p^2 + 2\gamma f^2 s. \quad (10.1)$$

The density matrix obeys  $\rho = \rho^\dagger$ ,  $\text{Tr} \rho = 1$ , and  $\rho \geq 0$ . The parameter  $f$  sets the gradient scale;  $\gamma$  and  $\alpha$  are dimensionless when  $h$  is dimensionless,  $V$  has energy-density units, and  $M_p$  is the reduced Planck mass. This covariant 3+1D ansatz still requires constrained variation on the admissible state space; the integral alone does not finish the equations.

Require  $F(s) > 0$  throughout. The equations must preserve trace and positivity, and the quadratic perturbation action must yield healthy kinetic terms and causal characteristics. Hilbert-space dimension alone determines no stress tensor.

### 10.2 Reduced scalar proxy

Use a local scalar proxy  $\varphi$  with energy units, e.g.  $\varphi = f(s - s^*)$  near a reference state. This is a small-excursion reduction:  $s \in [0, 1]$ , unlike an unconstrained canonical scalar. The reduced action is

$$S_\varphi = \int d^4x \sqrt{-g} [M_p^2 R/2 - \frac{1}{2} (\nabla \varphi)^2 - V(\varphi) + \alpha h(\varphi) \mathcal{G}] + S_m. \quad (10.2)$$

The scalar equation is

$$\square \varphi - V'(\varphi) + \alpha h'(\varphi) \mathcal{G} = 0. \quad (10.3)$$

The metric equation may be written in a sign-transparent form by defining the Gauss–Bonnet contribution through functional variation:

$$M_p^2 G_{\mu\nu} = T_{\mu\nu}(m) + T_{\mu\nu}(\varphi) + \alpha K_{\mu\nu}[h], \quad (10.4)$$

$$K_{\mu\nu}[h] \equiv -(2/\sqrt{-g}) \delta/\delta g^{\{\mu\nu\}} \int d^4x \sqrt{-g} h(\varphi) \mathcal{G}. \quad (10.5)$$

Equation (10.5) defines the sign in (10.4). In four dimensions, the constant-coefficient Gauss–Bonnet integral is topological, so  $K_{\mu\nu}$  vanishes for constant  $h$  (up to boundary terms) but can act when  $h$  varies. This modifies the equations; it does not prove a regular or stable solution.

### 10.3 Candidate potential and dimensions

$$V(\varphi) = \frac{1}{2} m \varphi^2 \varphi^2 + (\lambda/4) \varphi^4, \quad h(\varphi) = \varphi^2/(2f^2). \quad (10.6)$$

In natural units,  $[\varphi] = [f] = [m\varphi] = \text{energy}$ ;  $\lambda$  and  $\alpha$  are dimensionless, and  $[\mathcal{G}] = \text{energy}^4$ , so every Lagrangian term has energy<sup>4</sup> units.  $V$  is a test potential, not selected physics; its parameters must recover GR away from the throat and pass stability and observational checks.

This scalar proxy is not yet derived from the matrix action. A controlled map  $\rho(x) \rightarrow \varphi(x)$  must fix the kinetic normalization, potential, and curvature coupling; until then the two actions are alternative ansätze, not equivalent theories.

## 11. Curvature activation and the scalar–Gauss–Bonnet candidate

The Gauss–Bonnet invariant provides a useful curvature-sensitive quantity in four dimensions:

$$\mathcal{G} = R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} - 4R_{\mu\nu}R^{\mu\nu} + R^2. \quad (11.1)$$

A dynamical coupling  $h(\varphi)\mathcal{G}$  is a candidate extension because it makes the scalar equation respond to curvature beyond a simple linear  $R\varphi$  coupling. The constant-coupling integral is topological in four dimensions; the varying coupling allows local dynamics. Related scalar–Gauss–Bonnet theories have been studied as candidate settings for nontrivial compact-object and wormhole geometries [7]. That literature establishes that the mathematical direction has precedent, not that the specific qdit model works.

For the reduced action (10.2), the scalar equation is  $\square\varphi - V' + \alpha h' \mathcal{G} = 0$ . In a static, spherically symmetric spacetime, let

$$ds^2 = -e^2\Phi(r)dt^2 + dr^2/[1-b(r)/r] + r^2d\Omega^2,$$

$$\varphi(r) = \varphi_0 + \varphi_2 r^2 + O(r^4) \text{ near a regular center.} \quad (11.2)$$

At a regular center the leading spatial Laplacian gives  $\square\varphi|_0 = 6\varphi_2$  for this static expansion. The local consistency condition is

$$6\varphi_2 = V'(\varphi_0) - \alpha h'(\varphi_0)\mathcal{G}_0. \quad (11.3)$$

For  $h = \varphi^2/(2f^2)$ ,  $V = \frac{1}{2}m\varphi^2 + \lambda\varphi^4/4$ , and a de Sitter-like center with  $\mathcal{G}_0 = 24/\ell^4$ ,

$$\varphi_2 = \varphi_0/6 [m\varphi^2 + \lambda\varphi_0^2 - 24\alpha/(f^2\ell^4)]. \quad (11.4)$$

Equation (11.4) is a derived local center condition under its stated ansatz. It shows explicitly how curvature competes with the potential in the leading profile of the effective state field. It is not a complete black-hole solution: the independent metric equations must also be satisfied, the field must remain regular away from the center, and all perturbations must be healthy. A local expansion is a boundary condition for numerical integration, not proof that the global solution exists.

### Why this is not an automatic wormhole mechanism

The canonical scalar stress tensor obeys the NEC, while the throat benchmark requires effective radial NEC violation. The Gauss–Bonnet term changes the metric equations and can contribute to the effective source, so the canonical-scalar no-go argument does not settle the full action. But it also does not guarantee a traversable throat. The required next calculation is to vary the action, insert the two-ended ansatz, solve the coupled equations with mouth boundary conditions, and examine the perturbation equations. If no stable solution exists for a healthy parameter domain, that is the result; it should not be repaired by adding an unconstrained term solely because the original narrative wants a wormhole.

## 12. Central regularity conditions and the qdit-to-core test

A center expansion and a throat expansion are different problems. For a regular center in areal radius, use

$$\begin{aligned} m(r) &= m_3 r^3 + O(r^5), & \Phi(r) &= \Phi_0 + \Phi_2 r^2 + O(r^4), \\ \varphi(r) &= \varphi_0 + \varphi_2 r^2 + O(r^4). \end{aligned} \quad (12.1)$$

The mass function  $m(r)$  vanishes as  $r^3$ , preventing a  $1/r$  mass term from producing a central curvature divergence.  $\Phi$  and  $\varphi$  are even in  $r$  to leading order. The Einstein equations then relate  $m_3$  and  $\Phi_2$  to the finite central stress and pressure, while the scalar equation sets  $\varphi_2$  through (11.3). All central curvature invariants must remain finite. A single finite scalar  $R$  is not enough; one should examine a basis of invariants including  $R$ ,  $R_{\mu\nu}R^{\mu\nu}$ ,  $R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$ , and any additional invariants entering the action.

For a throat instead of a center, the natural coordinate is signed proper distance  $l$ , with

$$\begin{aligned} r(l) &= r_0 + r_2 l^2 + O(l^4), & \Phi(l) &= \Phi_0 + \Phi_2 l^2 + O(l^4), \\ \rho g(l) &= \rho_0 + \rho_2 l^2 + O(l^4). \end{aligned} \quad (12.2)$$

The condition  $r_2 > 0$  is the local flare-out. The density matrix remains trace-one and positive semidefinite. The qdit field equations and metric equations must jointly determine  $r_2$ ,  $\Phi_2$ , and  $\rho_2$ . If the qdit field requires negative norm, loses positivity, or produces a divergent stress tensor, the candidate fails even if the metric ansatz looks attractive.

### The qdit-to-core mapping obligation

A concrete map might identify the scalar proxy with a coarse-grained function of the hidden-subspace occupation,  $\varphi = f(s - s^*)$ , or with a function of several invariants  $q_A q_A$  and their derivatives. But the map must be derived or independently motivated. A mapping chosen after seeing the desired Hayward profile can reproduce it by construction and still have no predictive power. The discriminating test is whether the same action, with parameters fixed elsewhere, generates the finite-core behavior and also recovers the weak-field gravitational limit.

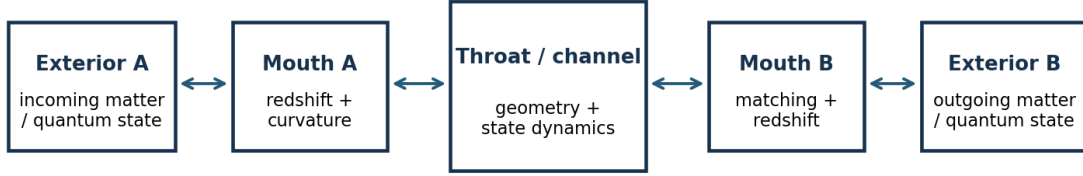
### Local and global gates

- Local center: finite metric functions, finite curvature invariants, and a consistent regular series solution.
- Global continuation: integrate outward without a hidden singularity, pathological branch, or unwanted horizon.
- Exterior recovery: approach the observed weak-field metric with constrained deviations.
- Source consistency: all metric constraints and qdit positivity conditions hold throughout the solution.
- Stability: linear perturbations have no unacceptable ghost, gradient, or exponentially growing mode in the intended regime.

The mathematics is demanding but not ambiguous. These conditions translate the proposal into a boundary-value and perturbation problem that can be handed to another researcher without requiring them to accept the TOE interpretation.

## 13. The computational channel: states, losses, and observables

**Geometry determines causal access; dynamics determines what is transmitted**



*Schematic only. It does not depict an extra spatial dimension or prove a physical wormhole.*

Figure 2. The intended channel architecture. Geometry determines whether causal access exists; a dynamical model determines the state map and the backreaction. The diagram is a system schematic, not a solved physical process.

The wormhole channel is an operational object only when input, output, environment, and observables are specified. For a closed qdit plus throat environment, write the full evolution as a unitary  $U$  on the joint Hilbert space. If the environment begins in state  $\sigma E$  and is not observed, the receiver's channel is

$$\mathcal{E}W(\rho_{in}) = \text{Tr}_E[UW(\rho_{in} \otimes \sigma E)U^\dagger]. \quad (13.1)$$

This map is completely positive and trace-preserving (CPTP) under the stated unitary-environment construction. It can encode mixing, decoherence, entanglement with the throat, and loss of accessible coherence without violating total quantum evolution. The reduced register need not remain pure and need not equal the incoming state.

### 13.1 The unitary limit

Along a prescribed path parameterized by proper time, a closed five-state register obeys

$$UW = \mathcal{T} \exp[-i \int H(\tau) d\tau]. \quad (13.2)$$

The time-ordering symbol  $\mathcal{T}$  is needed when  $H(\tau)$  does not commute with itself at different times. An explicit gate can mix basis states, for example

$$U\theta = \exp[-i\theta(|1\rangle\langle 4| + |4\rangle\langle 1|)]. \quad (13.3)$$

This is a mathematically valid unitary rotation between one state in the proposed classical-projection subspace and one in the additional subspace. It is a test circuit, not a physical prediction that a wormhole applies this gate. A physical derivation must connect  $\theta$  to the local interaction, path, curvature, and the system's backreaction.

### 13.2 A noisy channel with an exact fidelity benchmark

A simple benchmark combines ideal transport  $U$  with depolarizing noise of strength  $1-\eta$ :

$$\mathcal{E}\eta(\rho) = \eta U\rho U^\dagger + (1-\eta)I_5/5, \quad 0 \leq \eta \leq 1. \quad (13.4)$$

For a pure input  $|\psi\rangle$  and the ideal target  $U|\psi\rangle$ , the output-state fidelity is

$$F = \langle \psi | U^\dagger \mathcal{E}\eta(|\psi\rangle\langle \psi|) U | \psi \rangle = (1+4\eta)/5. \quad (13.5)$$

This is an exact result for the chosen depolarizing-channel model.  $\eta=1$  gives perfect unitary transmission, and  $\eta=0$  gives the maximally mixed output with fidelity  $1/5$  against a pure target. The model is useful because it makes “the wormhole transmits information” quantitative. It does not supply a value of  $\eta$ ; physical noise must be derived from the throat environment or measured in a candidate platform.

### 13.3 General open-system evolution

$$d\rho/d\tau = -i[H, \rho] + \sum_k \gamma_k [L_k \rho L_k^\dagger - \frac{1}{2}\{L_k^\dagger L_k, \rho\}]. \quad (13.6)$$

The Lindblad form is a controlled Markovian approximation when its assumptions hold.  $H$  is Hermitian;  $\gamma_k \geq 0$ ;  $L_k$  represent the coupling channels. A non-Markovian throat environment may require memory kernels or a larger environment. A proposed physical channel must identify which approximation is being used and quantify its regime of validity.

### 13.4 What is measured?

- State fidelity  $F(\rho_{\text{out}}, \rho_{\text{in}})$  and process fidelity of the reconstructed channel.
- Occupation transfer  $\Delta s$  and coherence transfer between  $P_2$  and  $P_3$ , with projection/measurement loss reported.
- Energy balance across the mouths, including energy deposited in throat modes and gravitational backreaction.
- Mode-dependent transmission for scalar, electromagnetic, and gravitational perturbations; no one transfer coefficient should be presumed universal.
- Quantum communication criteria such as distinguishability of outputs for distinct inputs, not a claim of faster-than-light signalling.

A computational channel adds a disciplined language for discussing what enters and exits. It does not make geometry irrelevant. The throat's causal structure must first permit a path; only then does a transmission map make sense.

Information is not an abstract passenger floating above physics. A quantum state is a physical state. If a wormhole carries a quantum system from  $A$  to  $B$ , its information content is carried in the joint state of the traversing degrees of freedom and the wormhole environment.

$$\rho_A \otimes \sigma_W \rightarrow \rho_B = \text{Tr}_E [ U_W (\rho_A \otimes \sigma_W) U_W^\dagger ]. \quad (13.7)$$

The channel is ideal only when the environment  $E$  remains decoupled or is controlled. In general the output is noisy. The right language is quantum channel theory: fidelity, entanglement fidelity, coherent information, classical capacity, and quantum capacity, subject to the physical energy and entropy costs of implementing the throat.

No-cloning remains intact. If an unknown quantum state is transported faithfully, the destination receives the state; the source does not retain an independent perfect copy generated by the transport process. A wormhole is not a loophole in linear quantum mechanics.

$$F(\rho, E(\rho)) = [ \text{Tr} \sqrt{ \sqrt{\rho} E(\rho) \sqrt{\rho} } ]^2. \quad (13.8)$$

In the ideal limit,  $F$  approaches 1 for the supported code subspace. In a realistic throat it falls below unity because of scattering, radiation, gravitational dressing, compactification leakage, and coupling to the throat support.

Entropy gives another constraint. For a system whose gravity is important, the amount of information that can be localized in a region is constrained by gravitational entropy bounds. The black-hole relation

$$S_{\text{BH}} = k_B c^3 A / (4 G \hbar). \quad (13.9)$$

is the canonical warning that spacetime geometry and information capacity are not independent bookkeeping systems. The TOE takes that clue seriously: a throat cross-section is simultaneously a geometric object, a gravitational object, and potentially a finite-bandwidth quantum channel.

#### THE BIG FLIP

In the TOE, a wormhole does not merely transport matter through space. It transports distinguishable physical state through a change in relational connectivity. Matter, energy, and information are different observables of one underlying state transition.

## 14. Traversal time, redshift, tides, and the shortcut test

In proper radial coordinate  $l$ , a static spherically symmetric wormhole metric is

$$ds^2 = -e^{2\Phi(l)} dt^2 + dl^2 + r^2(l) d\Omega^2. \quad (14.1)$$

Radial null curves satisfy

$$dt/dl = \pm e^{-\Phi(l)}, \quad \Delta t_{AB} = \int A^B e^{-\Phi(l)} dl. \quad (14.2)$$

For the symmetric two-mouth benchmark, the full null travel time between matching surfaces is

$$\Delta t_{WH} = 2 \int_{r_0}^{r_m} e^{-\Phi(r)} dr / \sqrt{[1 - b(r)/r]}. \quad (14.3)$$

Equation (14.3) is exact for the static geometry. The integral must be evaluated for a specific parameter set; the answer does not mean an external observer can send a signal faster than the local light cone. A shortcut claim compares the wormhole travel time to a specified external route between matched endpoints in the same reference convention:

$$\Delta T = \Delta t_{outside} - \Delta t_{WH}. \quad (14.4)$$

A positive  $\Delta T$  is meaningful only after the endpoints, clocks, external path, mouth trajectories, and metric are defined. For an arbitrary distance between widely separated mouths, “shorter path” is not a complete observable.

### Traveler proper time

For a massive radial traveler with conserved specific Killing energy  $E$  in a static metric,

$$dt/d\tau = E e^{-2\Phi}, \quad (dl/d\tau)^2 = E^2 e^{-2\Phi} - 1. \quad (14.5)$$

The proper transit time between the mouths is therefore

$$\Delta\tau = \int A^B dl / \sqrt{[E^2 e^{-2\Phi(l)} - 1]}. \quad (14.6)$$

The traveler’s clock is not the external coordinate clock. A numerical result requires an initial velocity or  $E$ , a finite mouth location, and the metric profile. A model that advertises a transit time without those inputs has not completed the calculation.

### Tidal forces and payload limits

For an extended payload, calculate components of the Riemann tensor in the traveler’s orthonormal frame. Relative acceleration between neighboring freely falling parts is governed by geodesic deviation,

$$D^2 \xi_\mu / D\tau^2 = -R_{\mu\alpha\nu\beta} u^\alpha u^\beta \xi^\nu. \quad (14.7)$$

The relevant engineering quantities are peak tidal acceleration across the payload, duration of the peak, and structural/biological tolerance of the particular object. “A person can pass” and “a gravitational wave can pass” are different claims. Different fields couple differently, and a background that is geometrically traversable can still produce intolerable tidal forces or absorption.

### Does a wormhole beat a light ray?

Locally, every signal remains inside the local causal cone of the metric or of the specified effective field equations. A wormhole can provide a global route that is shorter in a chosen comparison geometry, but the claim is only as good as the solved global metric and the comparison convention. No hidden spatial direction is needed to formulate this test. No faster-than-light local motion follows from it.

## 15. Causality, horizons, and the chronology trap

Traversability and chronology are separate conditions. If one mouth undergoes a different motion history or gravitational time dilation, the relation between its proper time and an external coordinate clock can shift relative to the other mouth. In idealized constructions, combining that shift with external paths can generate closed timelike curves (CTCs) [2].

CTC condition: a closed curve  $\gamma$  with  $g_{\mu\nu}(dx^\mu/d\lambda)(dx^\nu/d\lambda) < 0$  everywhere along  $\gamma$ . (15.1)

The inequality is only a local timelike condition; the curve must also close consistently in spacetime and satisfy the global geometry. No chronology-protection mechanism is assumed here. A real test must account for the complete throat metric, mouth motion, clock synchronization, quantum stress, and gravitational backreaction.

The event-horizon issue is even more direct. A static Schwarzschild exterior has a horizon at  $r=2M$ . Matching to a traversable mouth outside  $r>2M$  is possible in the benchmark because the interior replaces the Schwarzschild interior and the full lapse remains nonzero. The result is horizonless and therefore not a classical black hole. If the model insists on true event horizons around both mouths, it must show how signals can emerge without contradicting the definition of the event horizon. Merely calling each side a “black-hole mouth” does not solve the causal problem.

A responsible theory has three options if CTCs appear: derive a dynamics that prevents the required configuration from forming, demonstrate a consistent chronology constraint, or accept and analyze the causal pathology. It may not declare causality safe because the tunnel is computational.

## 16. Stability, energy inequalities, and physical admissibility

A regular metric is only the first gate. The constructed geometry has a finite throat, finite lapse, and explicit stress requirement. Nothing in those facts shows that small perturbations decay, that the source can exist in quantum field theory, or that the effective action remains valid at the curvature scale of the throat.

### Six distinct viability questions

- Background existence: do the full field equations admit the candidate solution with the required boundary conditions?
- Regularity: are all curvature invariants and all matter/qdit observables finite at the center or throat?
- Kinetic health: do propagating modes have positive kinetic energy and a well-posed initial-value problem?
- Gradient and radial stability: are the perturbation speeds and effective potentials acceptable, and are there growing modes?
- Quantum-energy consistency: can the required effective negative null stress be generated in the specified quantum state without violating applicable quantum inequalities?
- Effective-theory control: are curvature and derivative scales below the cutoff, or is the calculation being used outside its regime?

Quantum energy inequalities constrain how negative energy can be distributed and sampled in particular quantum field theories [5,8]. The bounds depend on the field, state, sampling, spacetime, and approximation; there is no universal one-number “negative-energy budget” that makes every wormhole impossible or feasible. A candidate must calculate the relevant bound for its own support mechanism.

Scalar–Gauss–Bonnet couplings offer a legitimate model-building route, but they can introduce strong coupling or unstable branches, depending on the parameters and background. The full quadratic perturbation action, characteristic speeds, and domain of validity must be reported. A successful background can fail this gate.

### No shortcut around the support problem

The proposed hidden qdit states cannot be declared “exotic matter” merely by name. Their contribution is the stress tensor derived from the action, including the sign of every kinetic term and every nonminimal coupling. If the contribution to  $T_{\mu\nu}k_{\mu}k_{\nu}$  is nonnegative in the relevant regime, it cannot supply the classical-GR throat requirement. If a modified-gravity term supplies the effective defocusing, the theory must still demonstrate healthy propagation and consistency with observation.

## 17. Predictions that could distinguish the model

A model becomes more than a relabeling when a parameter-fixed calculation produces an observation that differs from the baseline. The current qdit-wormhole model is not yet at that stage, but its potential observables can be enumerated without pretending to know their values.

| Observable class          | What must be calculated                                                     | What would count as a discriminating result                                                                      |
|---------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| Weak-field gravity        | Post-Newtonian metric and any extra-mode coupling at large $r$ .            | A parameter-linked deviation consistent with solar-system, binary, and laboratory limits.                        |
| Lensing and shadows       | Null geodesics and radiative transfer for a specified exterior.             | A predicted lensing/shadow feature not reproduced by an ordinary compact-object model with the same mass/spin.   |
| Ringdown and absorption   | Linear perturbation spectrum, boundary conditions, and mode transmission.   | A parameter-fixed frequency/damping or absorption prediction differing from GR within current constraints.       |
| Tidal response            | Metric perturbations and tidal Love numbers for the selected object family. | A reproducible relation to mass, throat scale, or qdit parameters that survives comparison with known mimickers. |
| Quantum-channel signature | Derived $\eta$ or process matrix for a physical input/output mode.          | A measurable transfer/noise relation tied to curvature, with an independently constrained coupling.              |
| Matter-flow response      | Time-dependent collapse/feeding solutions with flux and backreaction.       | A distinctive, stable response or a falsifiable instability threshold derived from the model.                    |

The theory should choose one near-term observable and work it through numerically, rather than advertise a menu of possibilities as if they were predictions. For the current stage, a reasonable target is a stability/existence boundary for the two-mouth family when its required source is coupled to a specific scalar–Gauss–Bonnet or matrix-field action. That calculation would directly test the proposed mechanism instead of only testing a selected metric.

Any predicted extra gravitational modes must also be compatible with observed gravitational-wave propagation and polarization constraints. The standard two-helicity limit must be recovered where it is already well tested [9]. “There may be additional computational states” is not itself an observable signature.

## 18. All Is Epistemic: the strongest defensible synthesis

Within the TOE, A0—ALL IS EPISTEMIC—serves as the sole philosophical premise. The working physical question is whether distinctions, relations, measurements, and state transitions can be used to construct a covariant account of spacetime and gravity. In this manuscript, that question is operationalized by a five-state register, a proposed map to a local state field, a curvature-dependent interaction, and a definite geometric test.

The phrase “matter enters a mouth and the gravitational sector reacts” can be given a standard mathematical meaning. Matter contributes to the stress-energy tensor. Curvature is determined by the metric field equations. A coupled qdit-associated field evolves under its local Hamiltonian/action. Its state changes the geometry only if its derived stress tensor or modified gravitational couplings change the metric equations. The reverse feedback is then solved self-consistently. This is a potentially fruitful program, but each arrow needs equations; none is licensed by analogy alone.

The strongest current synthesis is therefore modest in ontology and concrete in method: the five-state qdit provides a candidate internal state space, the 24 traceless generators provide a coordinate system for its density matrix, the covariant action defines how that system might couple to curvature, and the wormhole benchmark defines the stress and geometry the theory would have to produce. The mathematical bridge is explicit; the physical identity of its pieces remains open.

The Omega Inversion Principle (OIP) may be used as a cosmological hypothesis within the larger TOE, but it is not needed to derive the local two-mouth metric or the channel equations in this manuscript. It should not be inserted as a hidden boundary condition to force a wormhole solution. If OIP predicts a finite terminal state, that prediction must be separately specified and checked for consistency with local conservation, causal structure, and the chosen action.

Differentiate. Relate. Measure. Then test. The 3+1D simplification is not a retreat: it eliminates geometric machinery that was not earning its place and forces the proposal to explain the four-dimensional throat directly. The 24 are operators, not places. The five states are an encoding, not yet an observed graviton property. The throat is a solution only when the equations say so.

## 19. Reproducible solution program and pass/fail gates

The project now has a precise next computation. The benchmark geometry, target source, qdit state space, candidate field action, and channel object are all defined. The work should proceed in an order that prevents the chosen geometry from being mistaken for the output of the theory.

1. Specify the microscopic qdit-to-field map. State whether the field variable is the full constrained  $\rho(x)$ , the occupation scalar  $s(x)$ , 24 independent coordinates, or a justified reduced subset.
2. Write the complete covariant action with all dimensions, signs, symmetries, and boundary terms fixed. Derive the metric and state equations by variation.
3. Derive the static spherical equations in proper radial distance. Include all constraint equations and the full source from matter, qdit, and curvature couplings.
4. Set regular throat initial data:  $r(0)=r_0$ ,  $r'(0)=0$ ,  $r''(0)>0$ , finite lapse, finite state variables, and positivity/trace constraints. For a regular-center branch, use a distinct center expansion.
5. Integrate to both mouths and impose the asymptotic Schwarzschild matching conditions. Do not choose  $b(r)$  or  $\Phi(r)$  by hand and then claim the action predicted them.
6. Calculate the complete effective source and compare it with the geometric target from Chapter 6. Track  $\rho+p_r$  and the total conservation law.
7. Linearize the complete system about the background. Analyze radial and nonradial perturbations, kinetic signs, characteristic speeds, and strong-coupling scales.
8. Compute null geodesics, travel time, redshift, tidal tensors, and the chosen channel map. Include backreaction for any finite-energy payload.
9. Test global causality and chronology for the actual mouth worldlines and metric. Analyze whether flux-fed solutions remain static or evolve.
10. Fix parameters independently where possible, calculate at least one distinct observable, and compare it with current data and plausible compact-object alternatives.
11. Release equations, numerical tolerances, initial data, code, and failure cases so another researcher can reproduce the result.

### Research gates

| Gate            | Pass condition                                                    | Fail condition                                                                         |
|-----------------|-------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Definition      | Complete covariant action and state constraints.                  | An undefined state-to-metric map or inconsistent dimensions.                           |
| Existence       | Solved two-ended geometry from the stated field equations.        | Only a hand-selected metric or failed boundary-value problem.                          |
| Regularity      | Finite invariants and field variables everywhere on route.        | Hidden center/throat singularity or diverging source.                                  |
| Support         | Derived sector supplies the required effective defocusing.        | The source violates no relevant null condition and no modified field term replaces it. |
| Stability       | Healthy perturbation spectrum and a controlled regime.            | Ghosts, fatal gradient instabilities, or strong coupling at the claimed scale.         |
| Transport       | Computed channel and conservation-respecting payload propagation. | Unspecified output, uncontrolled decoherence, or energy-balance failure.               |
| Causality       | Global causal audit passed for all relevant mouth paths.          | Unaddressed horizon blockade or unsupported chronology claim.                          |
| Prediction      | At least one parameter-linked differentiating observable.         | Only a relabeling of known physics or an unconstrained fit.                            |
| Reproducibility | Independent numerical verification.                               | Unreported tuning, unstable numerics, or non-reproducible results.                     |

A failed gate is progress when it identifies exactly which assumption or coupling fails. The preferred repair is the smallest one justified by the discrepancy—not an automatic return to extra dimensions or an unconstrained hidden sector.

## Conclusion: the bridge is drawn; the engine must still be built

This expanded edition now gives the geometry a concrete target. The regular-center benchmark supplies a finite-curvature black-hole core. The two-mouth construction provides a regular throat, finite lapse, matched Schwarzschild exteriors, exact stress components, a quantified NEC violation, and reproducible travel-time integrals. The qdit layer supplies a five-state Hilbert space, 24 independent traceless operator coordinates, a curvature-mixing Hamiltonian, a covariant effective-action candidate, and well-defined quantum channels.

What it does not yet give is the decisive microscopic derivation: one fixed, healthy qdit-based theory that generates the required two-mouth source, survives perturbations, and produces a distinguishing observation. That gap is explicit and measurable. It is also the right next target. A paper bridge is easy; a consistent field equation that holds the bridge open is the real engineering.

No hidden spatial dimensions are needed to state the problem. No five-state register by itself creates a throat. No regular center by itself creates a second mouth. No elegant channel map proves that information or matter can traverse a physical wormhole. Each of those implications must be earned in sequence.

A0 remains the premise. The equations remain the test. Reality has veto power.

*“Differentiate. Relate. Measure. Then cross.”*

## Appendix A. Core four-dimensional equations

### A.1 Schwarzschild reference

$$ds^2 = -(1-2M/r)dt^2 + (1-2M/r)^{-1}dr^2 + r^2d\Omega^2, \quad K=48M^2/r^6. \quad (A.1)$$

### A.2 Hayward regular-core reference

$$f(r) = 1 - 2Mr^2/(r^3 + 2M\ell^2), \quad m(r) = Mr^3/(r^3 + 2M\ell^2). \quad (A.2)$$

$$R(0) = 12/\ell^2, \quad K(0) = 24/\ell^4, \quad \mathcal{G}(0) = 24/\ell^4. \quad (A.3)$$

### A.3 Morris–Thorne throat

$$ds^2 = -e^{2\Phi}dt^2 + dr^2/(1-b/r) + r^2d\Omega^2; \quad b(r_0) = r_0, \quad b'(r_0) < 1. \quad (A.4)$$

$$\rho = b'/(8\pi r^2), \quad p_r = [-b/r^3 + 2(1-b/r)\Phi'/r]/(8\pi). \quad (A.5)$$

$$\rho + p_r \text{ at } r_0 = [b'(r_0) - 1]/(8\pi r_0^2) < 0. \quad (A.6)$$

### A.4 Radial null travel time and massive transit

$$\Delta t_{AB} = \int A^B e^{-\Phi(l)} dl; \quad \Delta \tau = \int A^B dl / \sqrt{[E^2 e^{-2\Phi(l)} - 1]}. \quad (A.7)$$

### A.5 Qdit channel

$$\mathcal{E}(\rho) = \text{Tr} E[U(\rho \otimes \sigma_E)U^\dagger], \quad \mathcal{E}_\eta(\rho) = \eta U \rho U^\dagger + (1-\eta)I_5/5. \quad (A.8)$$

$$F_{\text{pure, target}} = (1+4\eta)/5. \quad (A.9)$$

### A.6 Candidate scalar–Gauss–Bonnet system

$$S = \int \sqrt{-g} [M_p^2 R/2 - (\nabla\varphi)^2/2 - V(\varphi) + \alpha h(\varphi)\mathcal{G}] d^4x + S_m. \quad (A.10)$$

$$\square\varphi - V'(\varphi) + \alpha h'(\varphi)\mathcal{G} = 0. \quad (A.11)$$

$$\varphi_2 = [V'(\varphi_0) - \alpha h'(\varphi_0)\mathcal{G}_0]/6 \text{ at a regular static center.} \quad (A.12)$$

## Appendix B. Reproducible two-mouth benchmark

Parameter domain:  $M > 0$ ,  $0 < r_0 < 2M$ ,  $r_m > 2M$ ,  $\Delta = r_m - r_0 \geq (5/4)(2M - r_0)$ . Define  $x = (r - r_0)/\Delta$  and  $S_5(x) = 6x^5 - 15x^4 + 10x^3$ .

$$b(r) = r_0 + (2M - r_0)S_5(x), \quad r_0 \leq r \leq r_m; \quad b(r) = 2M, \quad r \geq r_m. \quad (\text{B.1})$$

Define  $\Phi_m = \frac{1}{2}\ln(1 - 2M/r_m)$ ,  $d = \Delta M/[r_m(r_m - 2M)]$ ,  $e = \Delta^2[-2M(r_m - M)/(r_m^2(r_m - 2M)^2)]$ . Then

$$\Phi(r) = \Phi_m + (e/2 - 4d)x^3 + (7d - e)x^4 + (e/2 - 3d)x^5, \quad r_0 \leq r \leq r_m; \quad (\text{B.2})$$

$$\Phi(r) = \frac{1}{2}\ln(1 - 2M/r), \quad r \geq r_m. \quad (\text{B.3})$$

The full bridge is formed by a reflection-symmetric copy of the interior on the two sides, using signed proper distance  $l$ . The construction matches the exterior lapse and its first two derivatives and the shape function and its first two derivatives at  $r_m$ . The conservative  $\Delta$  bound ensures  $b(r) < r$  for  $r > r_0$ . At the throat,  $\rho = 0$  and  $p_r = -1/(8\pi r_0^2)$ , so the radial NEC is violated by exactly  $1/(8\pi r_0^2)$ .

Dimensionless test case:  $M = 1$ ,  $r_0 = 1$ ,  $r_m = 2.5$ . Then  $\Delta = 1.5$ ;  $\Phi_m = \frac{1}{2}\ln(0.2) \approx -0.80472$ ;  $d = 1.2$ ;  $e = -4.32$ . The minimum interior lapse  $e^2\Phi \approx 0.1078 > 0$ . Proper radial distance from throat to one mouth  $\approx 4.3401M$ . One-sided radial null coordinate transit time  $\approx 11.3414M$ ; full mouth-to-mouth coordinate time  $\approx 22.6827M$ . These values are reproducible geometry benchmarks only; no source field has been shown to generate them.

## Appendix C. Qdit dynamics and transition test

$$\rho = \rho^\dagger \geq 0, \text{Tr} \rho = 1; \quad s = \text{Tr}(\rho P_3). \quad (\text{C.1})$$

$$d\rho/d\tau = -i[H, \rho]; \quad ds/d\tau = i\text{Tr}(\rho[H, P_3]). \quad (\text{C.2})$$

If  $[H, P_3] = 0$ , then  $s$  is conserved. Curvature terms that are diagonal in the  $P_2/P_3$  split cannot on their own change the occupation statistic. A curvature-driven transition model requires an off-diagonal term, for example

$$H_{\text{mix}} = \sum_{a=1\dots 2, b=3\dots 5} [\kappa_{ab}|a\rangle\langle b| + \kappa^*_{ab}|b\rangle\langle a|]. \quad (\text{C.3})$$

$$P(a \rightarrow b) \approx \left| -i \int d\tau \langle b | H_{\text{mix}}(\tau) | a \rangle \right|^2, \quad \text{for weak mixing.} \quad (\text{C.4})$$

To turn (C.4) into a prediction, specify the covariant origin of  $\kappa_{ab}$ , the energy cutoff  $\Lambda$ , the background curvature history, the state preparation, and the measurement map. The Hamiltonian is not free to be retuned independently for every background if the model is to have predictive value.

An exact register-level example isolates the channel mathematics from the missing physical coupling. Let  $|1\rangle$  lie in  $P_2$  and  $|4\rangle$  in  $P_3$ , and define a two-state rotation:

$$U_\theta = \exp[-i\theta(|1\rangle\langle 4| + |4\rangle\langle 1|)]. \quad (\text{C.5})$$

$$U_\theta|1\rangle = \cos\theta|1\rangle - i\sin\theta|4\rangle; \quad P_{1 \rightarrow 1} = \cos^2\theta, \quad P_{1 \rightarrow 4} = s_{\text{out}} = \sin^2\theta. \quad (\text{C.6})$$

These probabilities are exact for this abstract unitary once  $\theta$  is specified. They demonstrate how population can transfer between the two subspaces. They do not calculate  $\theta$  from spacetime curvature, derive a physical wormhole, or guarantee that the output reaches the other mouth; those require the geometry-derived interaction and the open-system channel of Chapter 13.

## Appendix D. Channel reconstruction and fidelity

For a finite five-state register, process tomography reconstructs the CPTP map  $\mathcal{E}$  from a linearly complete set of input states and output measurements. The reconstruction must report statistical error, state-preparation-and-measurement error, and the convention used for the ideal target  $U$ .

$$\mathcal{E}_\eta(\rho) = \eta U \rho U^\dagger + (1-\eta) I_5/5. \quad (\text{D.1})$$

$$F(|\psi\rangle, U|\psi\rangle; \mathcal{E}_\eta) = (1+4\eta)/5. \quad (\text{D.2})$$

The depolarizing model provides a baseline for software verification. A physical wormhole proposal would have to predict the process matrix from throat dynamics, or provide a physical experiment capable of measuring it. Fidelity alone is not enough: energy conservation, causal accessibility, the output mode, and backreaction must be reported alongside the quantum state.

## Appendix E. Center versus throat: boundary-condition checklist

| Requirement         | Regular center                                                | Traversable throat                                                                                               |
|---------------------|---------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| Coordinate behavior | Use areal radius $r \rightarrow 0$ .                          | Use signed proper distance $l$ across $r(l)$ minimum.                                                            |
| Metric expansion    | $m(r)=m_3r^3+\dots$ , $\Phi=\Phi_0+\Phi_2r^2+\dots$           | $r(l)=r_0+r_2l^2+\dots$ , $r_2>0$ ; lapse finite.                                                                |
| Curvature           | All independent curvature invariants finite at $r=0$ .        | All invariants finite through $l=0$ and mouths.                                                                  |
| Source requirement  | Finite stress and pressures consistent with center equations. | Effective null stress violates the throat requirement in GR, or modified equations supply equivalent defocusing. |
| Global condition    | Continuation to exterior and horizon test.                    | Two-ended continuation, mouth matching, no route-blocking horizon.                                               |
| Dynamics            | Regular initial data and stable core.                         | Stable throat plus transport and causal audits.                                                                  |

A Hayward-like center cannot be substituted for a Morris–Thorne throat, and a throat cannot be called a center merely because  $r$  is a radial coordinate. Any hybrid solution must state its topology and coordinate atlas and solve a single global set of equations.

## Appendix F. Research-status ledger and decision tree

| Claim                                                                              | Current status                                                                                        | Required next result                                                                              |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 3+1D wormhole geometry is mathematically possible.                                 | Established at the level of explicit solutions to Einstein equations with suitable effective sources. | No new proof of possibility is needed; focus on source and stability.                             |
| Regular black-hole center is possible in a benchmark metric.                       | Derived in the Hayward reference family.                                                              | Derive the same behavior from the proposed qdit field equations.                                  |
| Five-state qdit is a physical property of the graviton.                            | Conjecture.                                                                                           | Lorentz/gauge-consistent identification, classical limit, observables, and empirical constraints. |
| The 24 traceless operators are compact spatial dimensions.                         | Rejected in this edition.                                                                             | No such identification is used or required.                                                       |
| Qdit dynamics supplies the negative null stress required at a throat.              | Open.                                                                                                 | Derive $T_{\mu\nu}$ or modified metric contribution and verify its sign at the throat.            |
| A stable, traversable wormhole follows from the combined action.                   | Not demonstrated.                                                                                     | Solve boundary-value problem and perturbation equations.                                          |
| The five-state channel describes information transfer through a physical wormhole. | Mathematical channel defined; physical map unproven.                                                  | Derive channel from interactions and geometry or measure it in a controlled analog/experiment.    |
| Black-hole event horizons allow ordinary outward transit.                          | No under classical GR.                                                                                | Change the causal structure and show how exterior constraints are still satisfied.                |

The decisive next milestone is not another broad narrative. It is one end-to-end calculation: a specified qdit action, a static two-ended ansatz, a derived stress tensor, a solved background, and a stability analysis. If the theory fails, the residual discrepancy should identify which coupling or microscopic assumption failed. The geometry-first solution in Appendix B provides a precise target for that calculation.

## Appendix G. What the wormhole can and cannot carry

*The transport table.*

| Payload                                                     | Can it cross?      | Necessary condition / TOE implication                                                                           |
|-------------------------------------------------------------|--------------------|-----------------------------------------------------------------------------------------------------------------|
| Massive classical matter                                    | Yes, conditionally | Timelike causal curve, finite tidal field, sufficient conserved energy, stable throat, acceptable backreaction. |
| Photons / EM radiation                                      | Yes, conditionally | Null geodesics or wave modes must transmit through the throat; aperture and scattering matter.                  |
| Quantum fields                                              | Yes, conditionally | Regular mode solution with nonzero transmission; quantum backreaction must remain consistent.                   |
| Electric charge                                             | Yes, but conserved | Charge can move between mouths/regions; gauge flux and Gauss constraints remain exact.                          |
| Neutrals / weakly coupled matter                            | Yes, conditionally | Same geometric and mode constraints; coupling can change detectability after exit.                              |
| KK / compact-sector excitations                             | Potentially        | Mode eigenvalue, throat overlap, and compactification selection rules must allow the state.                     |
| Gravitational waves                                         | Yes, conditionally | Regular spin-2 perturbation with nonzero transmission; polarization can be filtered.                            |
| TOE five-state graviton qdit                                | Potentially        | Infrared helicities $\pm 2$ should be recovered; extra states require appropriate mass/compact-mode access.     |
| Quantum information                                         | Yes, conditionally | A physical quantum channel must exist; fidelity, noise, energy, and entropy bounds apply.                       |
| Negative-energy support                                     | Not a free payload | Quantum inequalities and backreaction constrain magnitude, duration, localization, and stability.               |
| A causal signal faster than light locally                   | No                 | Traversability is global shortcut geometry, not local superluminal motion.                                      |
| Arbitrary information from nowhere                          | No                 | A wormhole transports state; it does not create an information source ex nihilo.                                |
| A conserved charge erased by transit                        | No                 | The complete gauge and constraint equations forbid arbitrary disappearance.                                     |
| A generic entangled state as a controllable message channel | No                 | Entanglement alone does not establish traversability or signaling.                                              |
| A traveler through a nontraversable ER bridge               | No                 | The bridge is not a causal shortcut; horizons/global structure block the trip.                                  |

The table deliberately uses "conditionally" more often than "yes." That is not cowardice. It is the correct mathematical posture. A geometry can be traversable while a particular mode is evanescent. A channel can exist while a particular payload exceeds the tidal or energy budget. The word "wormhole" names a geometry; it does not guarantee a universal transport service.

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## Final research-status note

We can now answer the original question with enough structure to make it dangerous.

*A wormhole does not ask what object you are. It asks whether your state is a legal solution of the geometry.*

Mass can cross. Light can cross. Classical fields can cross. Quantum states can cross. Gauge charge can cross while remaining conserved. Gravitational waves can cross. Under the TOE, compact-sector excitations may cross as well. Information crosses whenever a physical quantum channel crosses.

But the throat is selective. Geometry chooses which geodesics exist. The wave equation chooses which modes transmit. Compactification chooses which internal states are available. Gauge symmetry chooses which state transformations are legal. Energy conditions choose whether the throat can remain open. Quantum inequalities constrain the support. Backreaction changes the geometry as the payload passes. Causality constrains the global history.

The deepest TOE claim is therefore not that wormholes are magic shortcuts. It is that transport, geometry, information, and computation are manifestations of one relational substrate. If all is epistemic, then a wormhole is an extreme physical realization of the K3 kernel: it creates a new lawful distinction - this region versus that region - establishes a relation between them - the throat - and permits invariant measure along the resulting causal channel.

This is a speculative theoretical research manuscript. Established relativistic and quantum-information machinery is used to build explicit reference problems. The Hayward geometry and the two-mouth bridge are mathematical benchmarks; the qdit, its coupling to curvature, and the proposed role of the epistemic field are conjectural until they emerge from a complete and consistent microscopic model. The exact source required by the two-mouth geometry has been calculated, but its derivation from the proposed qdit action remains open.

The strongest conclusion is not that a physical wormhole has been solved. It is that the problem is now stated in a way that can be solved or falsified: a fixed action must yield the needed geometry, source, stability, channel, and observables. The model does not get to change the rules after seeing the result.

*A0 is the premise. The model is the test. Reality has veto power.*

### RESEARCH STATUS

This is a speculative theoretical manuscript. Established relativity and quantum-field results are used as constraints and reference points. The I-field interpretation, five-state graviton qdit as a fundamental computational register, emergent time, OIP, and the proposed wormhole-as-computational-channel interpretation are TOE hypotheses requiring derivation and experimental confrontation.