Wormhole Theory

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Wormhole Theory Research Report

Abstract

This report reviews a computational research program that tested whether a traversable wormhole can be supported without negative-energy matter or an unhealthy substitute. The evidence covers a geometry laboratory, analytic checks, numerical boundary-value and continuation studies, energy-condition audits, and stability diagnostics. Several published global wormhole geometries were independently reproduced, and a number of local field-equation and numerical controls passed. However, no candidate in the archive passes the full set of requirements for a globally regular, source-consistent, dynamically healthy, stable traversable wormhole. The strongest global mathematical branches stop at specific physical gates: an irregular canonical sector, a tensor ghost, a singular auxiliary map or reconstructed action, or an uncomputed coupled perturbation spectrum. The work therefore establishes substantial computational progress and several bounded negative results, but neither a physical wormhole nor a general no-go theorem for all gravitational theories.

What found

- In four-dimensional general relativity, a regular static flare-out throat requires a negative radial null contraction of the Einstein source. Reshaping the tested smooth GR profiles redistributes this requirement but does not remove it.
- Finite-grid and local passes are common and useful: the code verifies exact solutions, throat expansions, constraints, coordinate conversions, and convergence on declared domains. None of these local passes alone establishes global physical viability.
- Several globally defined mathematical solutions exist in the literature and were reproduced. Each retains a concrete limitation in source interpretation, effective energy, action regularity, canonical health, or full stability.

Purpose and Scope

The research question was deliberately stronger than whether a chosen metric can be drawn with a throat. A candidate had to connect two exterior regions, remain horizonless and regular, follow from an explicit covariant action and its complete field equations, identify its physical source, and pass the relevant energy, constraint, and dynamical-health checks. The initial target was a regular-source wormhole: a solution whose support does not depend on a phantom field or an unexamined negative-energy source. The report separates four levels that are often conflated: a wormhole-shaped metric; a solution of a stated background equation set; a globally matched solution of a specified theory with an identified source; and a stable, physically controlled configuration.

Assessment Criteria

The archive uses a staged acceptance contract. A global candidate must have two exterior ends, a positive finite lapse, a nonzero minimum areal radius, finite curvature, and no horizon on the claimed domain. It must satisfy the covariant background equations and constraints, with residuals checked independently of the equations used to evolve or fit it. The bare matter tensor is evaluated separately from effective curvature or torsion terms moved to the geometric side of the equations. Claims about health additionally require positive kinetic terms, well-defined constraints and characteristic evolution, and a coupled perturbation analysis with appropriate boundary conditions. Quantum-inequality claims require a specified quantum field, state, renormalized stress tensor, observer, sampling function, and regime of validity.

For the Morris-Thorne metric, the throat conditions include $b(r_0)=r_0$ and $b'(r_0)<1$. In ordinary 4D general relativity, the radial null contraction at the throat is

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

This establishes a local NEC violation for the declared GR class. It does not establish that the energy density ρ itself is negative in every model. In modified gravity, the report therefore tracks bare matter NEC separately from effective Einstein-tensor NEC.

Computational Method and Validation

The Wormhole Geometry Lab was developed as a symbolic and numerical environment rather than a picture generator. The development records describe Morris-Thorne and proper-radial metric representations, formula parsing, tensor and curvature calculations, throat and horizon diagnostics, geodesic integration for massive particles and light, observer and ray-bundle views, energy-condition profiles, and dynamic time-slice experiments. Visual embedding profiles are explicitly separated from the physical metric used by the field equations. Prescribed time dependence is labelled as kinematic unless a matter model, evolution equations, and constraints are solved together. Later research layers added action-derived residual evaluators and branch-specific audit contracts for Einstein-Cartan, scalar-tensor, Einstein-Dirac, Einstein-scalar-Gauss-Bonnet, beyond-Horndeski, thin-shell, Lovelock, conformal-gravity, semiclassical, Einsteinian cubic gravity, and EiBI models. Where a solver used a finite interval or finite grid, the report retains that qualification. Numerical convergence is treated as evidence about the calculation on the tested interval, not as proof of a limit at infinity. The archive records progressive regression counts, culminating in 518 passing tests after the finite-action beyond-Horndeski branch. One important correction was also logged: an independent reduced Einsteinian Cubic Gravity right-hand side had derivative slots in the wrong order. The affected pre-correction continuation records were explicitly superseded and excluded from the physical conclusions. This correction is included here because it changes which numerical branch results remain usable.

Results by Research Route

General Relativity and the Energy Budget

The Ellis-type control geometry passes the declared geometric checks but requires negative radial NEC. A separate exact calculation for a smooth zero-redshift, proper-radial family found a nonzero integrated effective-NEC budget in the limit that narrows the flare. For the stated convex, two-ended, unit-slope class, the derived lower bound is $B \geq 16\pi r_0/\kappa$. At $r_0=2$ and $\kappa=8\pi$, the numerical integral was 4.2454822556 against the analytic lower bound 4.0. This is a shape-independent result only under the stated assumptions; it is not a theorem for modified gravity. The quantum-inequality modules were kept within their actual scope. They compare selected samples with a flat-space Ford-Roman reference for a specified free field and sampling function. They do not turn the classical effective Einstein tensor or a Gauss-Bonnet remainder into a quantum stress tensor, and they do not certify a curved-spacetime quantum inequality. Unknown tails and out-of-scope comparisons remain inconclusive.

Einstein-Cartan and Scalar-Tensor Models

The reduced Weyssenhoff spin-fluid closures repeatedly passed local source and conservation checks while requiring a negative effective NEC at a flare-out throat. None of the tested isotropic barotropic or anisotropic closures produced a finite two-ended tail: the reported anisotropic scan had 50 completed cases and zero tail passes. These are rejections of the declared reduced closures, not of every Einstein-Cartan theory. Two different exact Einstein-Cartan branches give complementary results. One published scalar-torsion construction reproduces its radial equations but has a torsion invariant singular at the throat. Another symmetric branch passes finite-domain background equations and bare NEC/WEC/DEC checks for its reference parameter. Its endpoint coefficient $H=1/(1+x^2)$, however, tends to zero at both asymptotic ends. The tensor Planck coefficient and the action weights for radius perturbations therefore degenerate, so the branch is not certified as a globally healthy theory. Finite-box probe spectra do not repair that endpoint problem. A scalar-tensor model produced a finite-interval solution with positive matter energy conditions, $F>0$, and a positive Einstein-frame kinetic coefficient. The integration did not match an asymptotically flat exterior. Under the report's stated global assumptions, a separate conformal-frame argument gives a finite healthy-frame obstruction: canonical scalar and NEC-respecting matter do not provide the negative null focusing required for a regular flare-out. This is not a no-go outside those assumptions.

Einstein-Dirac and Thin-Shell Models

The analytic massless Einstein-Dirac-Maxwell control has a smooth local throat, but the throat geometry requires a negative radial Dirac-sector NEC; the exact massless spinor limit is not normalizable . In the neutral Einstein-Dirac scan, eight cases had both a sampled throat and a passed finite constraint. All eight had negative throat radial NEC and negative finite radial ANEC, while none met the reflection objective or passed a global two-ended matching gate. A later charged Einstein-Dirac-Maxwell collocation produced a regular finite segment but failed the independent Einstein constraint. These outcomes do not exclude all massive or charged branches; they identify the missing boundary-value and source gates for the cases tested. The Schwarzschild thin-shell family retains negative surface density throughout its positive-lapse domain. Its surface NEC changes sign, but the density does not. In the declared reference range of the shell equation-of-state slope, no point passes the analytic radial stability threshold across the full compactness interval. The separate finite-thickness quantum-scale study does not certify a quantum-compatible shell and shows that the selected thin-layer budget becomes incompatible at larger radii.

Gauss-Bonnet and Beyond-Horndeski Models

The Einstein-scalar-Gauss-Bonnet work improved the local and numerical contracts substantially. The regular throat series passes all four local Appendix-A residuals to floating-point precision on tested controls. Constraint-controlled finite segments were obtained, and energy bookkeeping consistently separated the nonnegative canonical scalar sector from the negative effective NEC carried by the Gauss-Bonnet term. The selected asymptotically flat parameter scans did not pass the two-ended Robin or lapse-matching gates. Frozen test-scalar modes were not treated as coupled stability results. Several exact published EsGB-Maxwell geometries were independently reproduced with small field-equation residuals and regular two-ended metrics. In these branches the stated canonical scalar and ordinary Maxwell or nonlinear-electromagnetic matter conditions can pass, while the effective Gauss-Bonnet sector supplies negative radial NEC. The reconstructed covariant coupling becomes singular at a finite scalar endpoint in the audited examples. Their full coupled spectrum and global action regularity therefore remain unestablished. The exact disformal beyond-Horndeski metric also passes its global two-ended geometric checks , but its transformed covariant action has a singular surface and divergent endpoint functions. Finite polynomial action reconstruction maintained positive tensor coefficients but failed the background residual gate, with a converged residual near 0.386. Earlier unitary-gauge high-energy coefficient controls and finite odd-sector spectrum checks are component-level diagnostics; they do not provide the missing complete covariant solution or coupled even-sector spectrum. A source-inclusive Einstein-dilaton-Gauss-Bonnet construction produced a global distributional two-ended background with explicit throat surface stress. The reported dust specialization has positive surface density and passes local surface NEC/WEC/DEC checks. It is not a smooth vacuum throat, its source is essential, and the full bulk-plus-shell perturbation spectrum remains uncomputed. It is therefore the clearest source-inclusive global candidate in the archive, but not a stability-certified physical solution.

Global Higher-Dimensional and Alternative-Theory Solutions

The smooth five-dimensional Chern-Simons Lovelock vacuum branch is the strongest global mathematical result in the archive. An independent field-equation calculation gives a maximum residual of 5.68×10^{-13}, with two asymptotically locally AdS ends, positive lapse, finite sampled curvature, and no horizon. The fast-falloff massless probe scalar has a positive lowest eigenvalue for the tested boundary condition. However, the local canonical audit gives symplectic rank 24 of 56 and constraint rank 12 of 15. The standard coupled gravitational perturbation problem is consequently irregular or undefined in the tested sector; nonlinear stability is open. Replacing the compact base by Sol or Nil preserves the geometry but not the rank defect. The five-dimensional EGB-Maxwell construction is a global piecewise mathematical solution with two regular exteriors and explicit Lovelock junction conditions. Maxwell matter passes NEC/WEC/DEC, with radial NEC and ANEC saturated; the scalar or radial junction stability test passes. An independent tensor audit finds a wrong-sign kinetic coefficient in the interior and a high-angular-momentum instability condition near the exterior junction. Full linear stability therefore fails despite the matter-sector pass. Other global reproductions include an exact AdS quotient wormhole, a four-dimensional conformal-gravity vacuum branch, and a tuned Palatini EiBI-Maxwell geon. Their limitations are distinct: the AdS quotient's effective cosmological source fails WEC/DEC; conformal gravity has a generic ghost sector; and the EiBI geon's auxiliary metric map degenerates at the throat, blocking a full metric-connection perturbation certificate. These are reproductions of published mathematical branches, not new discoveries or validated devices.

Branches Not Yet Globally Established

The Einsteinian Cubic Gravity effort now has an action-derived, regular proper-distance local throat series and convergent short two-sided segments. Several independent continuations stop before an asymptotic exterior because of a rank-deficient principal system or non-removable implicit branch termination. After the reduced-chart derivative-order bug was corrected, pre-correction results were withdrawn and corrected branches were rerun. No global ECG solution was established. The five-dimensional string-cloud claim was rejected analytically because its proposed throat has zero lapse and is a Killing horizon. Single-source canonical-scalar formation in spherical GR passed selected finite-grid energy conditions but did not produce a second asymptotic end; at larger amplitude the constraint drifted. Semiclassical and fermion-Casimir branches likewise lack a globally matched, stable source model in the supplied audits.

Results Matrix

The table summarizes the strongest outcome for each major route. "Pass" always applies only to the stated calculation and domain.

Research route	What was established	Remaining decisive limit
4D general relativity	Exact throat NEC relation; nonzero smooth-profile NEC budget for the declared class.	Negative effective radial NEC remains; no ordinary-GR regular-source candidate.
Einstein-Cartan	Local and finite-domain action/background checks; some bare-source conditions pass.	Reduced closures lack two-ended tails; exact branch has degenerate tensor/action weights at infinity.
Scalar-tensor	Finite-interval WEC/NEC-positive local control and healthy finite-grid kinetic factor.	No global asymptotic match; conformal-frame obstruction under declared assumptions.
Einstein-Dirac	Analytic and finite-grid throat controls; constraints and parity are audited explicitly.	Negative radial NEC/ANEC in qualified throats; no accepted global seam or full spectrum.
EsGB and beyond-Horndeski	Local throat series, finite residuals, exact global metric reproductions, source/effective NEC separation.	Selected branches fail global matching or action regularity; complete coupled stability is open.
5D Chern-Simons Lovelock	Smooth global two-ended vacuum geometry; independent residual below 6×10^{-13}.	Canonical and constraint ranks are deficient; standard coupled spectrum is blocked.
5D EGB-Maxwell	Global piecewise geometry; Maxwell energy conditions and scalar/junction mode pass.	Wrong-sign tensor kinetic coefficient and local tensor instability.
EGBd with throat source	Global distributional background with explicit positive surface source checks.	Source is essential; full bulk-plus-shell perturbation spectrum is unknown.
EiBI-Maxwell geon	Published two-ended physical metric independently reproduced; Maxwell conditions pass.	Auxiliary map degenerates at the throat; full stability is uncertified.

Research route	What was established	Remaining decisive limit
Other exact branches	AdS quotient and conformal-gravity backgrounds reproduce globally.	Cosmological WEC/DEC failure or a generic higher-derivative ghost sector.

Software and Research Products

The engineering outcome is a reusable laboratory that makes assumptions and claim boundaries visible. It includes a symbolic/numeric metric engine, user-editable metric inputs, a desktop embedding and particle viewport, proper-radial geodesics, CPU null-ray tracing, curvature and energy plots, unit-conversion diagnostics, and separate reports for source, horizon, stability, and quantum status. The central safeguard is that rendering does not determine the physics: a visual flare profile can be rendered without being treated as a solution of a field equation.

Overall Conclusion

The research has not found a fully validated traversable wormhole that avoids negative-energy support and also satisfies global regularity, a complete source theory, a healthy dynamical sector, and stability. The main positive result is a portfolio of reproducible mathematical and computational controls: the ordinary-GR obstruction is quantified; published global branches are independently checked; local successes are separated from global claims; several candidate mechanisms are rejected for explicit reasons; and a small number of source-inclusive or higher-dimensional global geometries remain mathematically viable but dynamically unresolved or unhealthy. The strongest current global geometry is the smooth Chern-Simons Lovelock vacuum branch, but its canonical degeneracy blocks an ordinary stability certificate. The strongest explicit-source branch is the distributional EGBd solution with a positive throat surface source, but its coupled stability is open. The EGB-Maxwell branch passes its matter and scalar/junction tests but fails the tensor-health gate. None can currently be described as a stable, physically realizable portal. These results do not prove that wormholes are impossible in every theory. They show that a throat, a positive local density, a converged finite segment, a low residual, or a successful test suite is insufficient by itself. Any next candidate must begin with an explicit action and preserve separate global geometry, source, constraint, asymptotic, perturbation, quantum, and scale gates.

Selected References

1. Morris, M. S., and Thorne, K. S. “Wormholes in spacetime and their use for interstellar travel.” American Journal of Physics, 56, 395–412 (1988). doi:10.1119/1.15620.
2. Hochberg, D., and Visser, M. “The null energy condition in dynamic wormholes.” Physical Review D, 58, 044021 (1998). arXiv:gr-qc/9802048.
3. Ford, L. H., and Roman, T. A. “Quantum field theory constrains traversable wormhole geometries.” Physical Review D, 53, 5496 (1996). doi:10.1103/PhysRevD.53.5496.
4. Bronnikov, K. A., and Galiakhmetov, A. M. “Wormholes without exotic matter in Einstein-Cartan theory.” arXiv:1508.01114 (2015).
5. Blázquez-Salcedo, J. L., Knoll, C., and Radu, E. “Traversable wormholes in Einstein-Dirac-Maxwell theory.” arXiv:2010.07317 (2020).
6. Weinbaum, S. “Obstructions to Traversable Wormholes in Einstein-Dirac Theory.” arXiv:2607.28738 (2026).
7. Kanti, P., Kleihaus, B., and Kunz, J. “Stable Lorentzian Wormholes in Dilatonic Einstein-Gauss-Bonnet Theory.” Physical Review D, 85, 044007 (2012). arXiv:1111.4049.
8. Cuyubamba, M. A., Konoplya, R. A., and Zhidenko, A. “No stable wormholes in Einstein-dilaton-Gauss-Bonnet theory.” arXiv:1804.11170 (2018).
9. Anabalón, A., and Oliva, J. “Four-dimensional Traversable Wormholes and Bouncing Cosmologies in Vacuum.” Journal of High Energy Physics, 2019(4), 106 (2019). arXiv:1811.03497.
10. Dotti, G., Oliva, J., and Troncoso, R. “Static wormhole solution for higher-dimensional gravity in vacuum.” Physical Review D, 75, 024002 (2007). arXiv:hep-th/0607062.
11. Giribet, G., Rubín de Celis, E., and Simeone, C. “Higher curvature wormholes.” Physical Review D, 100, 044011 (2019). arXiv:1906.02407.
12. Oliva, J., Tempo, D., and Troncoso, R. “Static wormholes in vacuum for conformal gravity.” International Journal of Modern Physics A, 24, 1528–1532 (2009). arXiv:0907.1128.
13. Maldacena, J., Milekhin, A., and Popov, F. “Traversable wormholes in four dimensions.” arXiv:1807.04726 (2018).
14. Bakopoulos, A., Charmousis, C., and Kanti, P. “Traversable wormholes in beyond Horndeski theories.” Journal of Cosmology and Astroparticle Physics, 2022(5), 022. arXiv:2111.09857.
15. Soulas, G. C., Haag, T. W., Herman, D. A., Huang, W., Kamhawi, H., and Shastry, R. “Performance Test Results of the NASA-457M v2 Hall Thruster.” NASA/TM—2012-217711; AIAA—2012-3940 (2012). Cited here as the supplied document-format reference.