What the Fabric of Spacetime Is Made Of

An engineer's proposed material account of gravity

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Put a book on a table. Lift it onto a shelf. Let it fall.



The story begins with an ordinary book. Lifting, holding, and releasing it connect energy, matter, and motion.

There is nothing unfamiliar about these actions. Yet an ordinary book puts several of gravity's deepest questions within reach. What held it together while it moved? Where did the energy supplied by your arm go? What changed when you raised it? Why would an ideal accelerometer, an instrument that measures how a body is pushed away from free fall, read zero on the falling book even as it gained speed toward the floor?

Now put a sufficiently precise clock on each shelf. The higher clock accumulates time a little faster. Send light past the Sun and its path bends. Watch two freely falling objects over a sufficient distance and their separation changes. We describe these observations by saying that gravity slows time, bends light, and curves spacetime. The phrase fabric of spacetime gathers those relationships into a powerful image. But the familiar picture of a heavy ball on a rubber sheet leaves a question unanswered: what is the sheet made of?

Operational Quantum Gravity, or OQG, begins with the things doing the observing and the things being observed. Both are physical. Clocks are made of matter. Rulers are made of matter. Light is an electromagnetic field excitation. Matter contains charges and currents, has quantum states, stores energy, and responds to its surroundings. Those facts become the starting point for the gravitational description.

The proposal is that matter's shared electromagnetic environment changes its balanced exchange of energy with the field, and that matter adjusts its equilibrium in response. The adjustment links its dimensions, internal frequencies, inertia, and recoverable energy. Inertia is its resistance to a change in motion; recoverable energy is energy that can be returned as useful work. Spatial differences in the stored energy govern motion. The clocks and rulers used to describe that motion participate in the same physical response. Geometry records the resulting relationships.

I developed Operational Quantum Gravity to connect material processes with gravitational observations. This article follows power balance through stable matter, stored energy, clocks, and free fall. The derivation appears in *Operational Quantum Gravity: From Electromagnetic Power Balance to Gravitational Response*, a preprint submitted to Classical and Quantum Gravity. [1] Its mathematical relationships are proved under stated conditions. The physical mechanism remains a proposal; its microscopic realization and absolute gravitational strength still require independent calculation and testing.

The question running through these pages is simple: when we say that spacetime does something, what is physically taking place? The book gives us a way to follow the answer.

Begin with the receiver

Imagine a receiver in a room containing an electromagnetic field. Its response depends on the field that reaches it, its own structure, and the frequencies to which it responds. Bring another object into the room. That object responds to the field too. Its charges move, and the field associated with that motion becomes part of the field at the first receiver.

An engineer recognizes this immediately. Nearby structures can change an antenna's reception. Two

antennas cannot always be treated as independent devices sitting in an unchanged background. The field drives currents; the currents change the field; the changed field acts back on the currents. The answer belongs to the coupled system.

For OQG, matter plays this receiving and responding role at the nuclear scale. Atomic nuclei possess charge and current responses determined by their quantum states. These responses couple to the local electromagnetic field. Surrounding matter modifies that shared field through scattering, the field produced as its charges respond. The material equilibrium therefore depends on both the receiver and its electromagnetic surroundings. [1]



A visual metaphor for shared field exchange. Matter responds locally; scattering and interference change the field received by other matter.

Calling this a field does not introduce another kind of mechanical cloth. An electromagnetic field specifies physical quantities that act on charges and currents and can carry energy and momentum. Its quantum description includes fluctuations and correlations, including those of the vacuum state. Empty of ordinary particles does not mean absent from the field theory.

A picture of tiny broadcasters and receivers is helpful if we remember what it represents. There need not be a separately aimed beam from every distant proton to every other proton. Each system couples locally to the shared field, and changes in that field propagate causally. Nor should the vacuum be imagined as a cloud of ordinary light packets available to scoop into a battery. The calculation concerns the quantum field and the response of the coupled matter, with the corresponding energy accounting.

The word supporting needs particular care. A stationary state can have balanced inward and outward contributions to its exchange with the field. In OQG's response description, the power entering the internal material motion equals the power leaving it. Their common value is the supporting power. Power is energy exchanged per unit time. Because the two sides balance, the stationary body has no net heating.

Zero net power and zero exchange are different statements. Two equal readings can subtract to zero without either reading being zero. The issue is then whether the common value remains the same when the surroundings change. OQG asks what happens when a different environment supports a different equilibrium exchange.

This does not make a stable quantum state into a classical electron orbit that must be continually rescued from radiative collapse. The incoming and outgoing terms belong to a complete quantum response calculation. It includes field fluctuations; radiation reaction, the effect of emitted radiation on the emitter; and correlations, the linked variations of interacting quantities. Treating only one contribution would describe a different physical problem.

The same distinction separates supporting power from mechanical power. A book resting on a shelf is doing no mechanical work through vertical motion. That tells us about its motion and the support force. It does not establish that all of its microscopic field exchange has ceased. Likewise, balanced microscopic exchange does not mean that the book is continuously consuming its stored gravitational energy. A settled equilibrium and a change between equilibria have separate energy accounts.

Can the exchange that helps set the book's internal state also explain the work of lifting it and the path of its fall? That is the connection OQG sets out to calculate.

How another body changes the balance

Scattering is often pictured as a small particle bouncing off an obstacle. That picture can be useful, but it misses the feature that matters most here: electromagnetic fields combine as waves. Their amplitudes and phases determine how they reinforce or oppose one another at a receiver.

Two contributions can each be present while their combination drives the receiver less strongly. Familiar interference experiments show the principle. A reduction at one receiving location does not mean that energy has disappeared. The full field, the other

receivers, radiation, and any change in storage must all be included in the balance.

Operational Quantum Gravity: From Electromagnetic Power Balance to Gravitational Response makes this concrete with two resonant electric dipoles: systems driven at a frequency where their charge separation responds strongly. Each receives the incident field and the field scattered by its partner. At the stated parameters, the interference reduces reception more than the added scattered intensity increases it. The absorbed power falls by about 0.07546 percent. That result demonstrates reduced reception in this example; the percentage is not Earth's gravitational deficit. [1, 2]

This belongs to the physics of dispersion forces, which arise from correlated electromagnetic fluctuations and the frequency-dependent response of matter. An object changes the field available to another object, and their joint energy can depend on their separation. Scattering calculations account for both the material response and repeated field exchange. OQG uses this physics to address the gravitational response of complete matter. [3]

There is a demanding consistency condition. A field has modes, or patterns of oscillation. If modes are equally populated, simply mixing them without loss or any change in the complete response does not automatically reduce the equilibrium exchange. The proposed gravitational mechanism must be calculated for the coupled field and matter, including all relevant inward and outward contributions. The receiver's adjusted state must be included in the calculation of the field to which it responds.

What does the receiver do when its equilibrium changes? It still has to be a bound physical system. Its charges and currents must settle into a state with a consistent restoring response and energy. OQG expresses part of this response in language an electrical engineer already knows: capacitance, inductance, and stored energy.

A nuclear capacitance describes electric energy storage; a nuclear inductance describes the energy and inertia associated with charge motion. There are no manufactured capacitors or coils inside the nucleus. These quantities are derived from the energies needed to excite its quantum states and from how strongly charge responds through those transitions. The electrical description organizes the same nuclear response in measurable storage quantities. [1]

The strong interaction remains in the nuclear states and their binding. An electrical account of the response does not erase that physics. A complete body's energy includes its constituents and their interactions; its gravitational behavior cannot be obtained by counting visible electric charge alone. Electrically neutral matter still contains charges, currents, and quantum responses.

Scaling matter and volume

The changed equilibrium must still describe bound matter, held together by its internal interactions. OQG constructs a family of corresponding quantum states by rescaling their lengths and rates of evolution. All changes are expressed in the same reference clocks and rulers. Under the theorem's conditions, a stable energy minimum remains stable: a small displacement from the new equilibrium still costs energy. The body can change scale while retaining its binding. [1]

Within that family, the supporting-power ratio is proved to equal the square of the clock-frequency ratio. Each ratio compares a state with the same reference state. Once the frequency ratio is specified, the power ratio is fixed. The proof maps the current patterns and the full equilibrium response, including radiation reaction, fluctuations, and correlations, consistently between the states. [1]

For an intentionally exaggerated numerical illustration, a frequency ratio of 0.99 corresponds to a supporting-power ratio of 0.9801. A one-percent frequency reduction therefore corresponds to a little less than a two-percent power reduction. Actual gravitational comparisons near Earth involve vastly smaller fractions. The illustration is only a way to see the square relationship without algebra.

The common scaling branch is the family in which dimensions and clock frequencies change by the same factor. Complete material energy carries that factor too. The capacitance and inductance vary together. Each scales as the inverse of the common factor, so both increase when size and frequency fall. Permittivity and permeability describe the electric and magnetic field response. Each scales as the inverse square of that factor, because converting component storage to field response also includes the changing geometry. [1]

An ordinary capacitor with fixed material properties does not capture that entire transformation. Here both the geometry of the responding state and its electromagnetic response change. Asking what happens to a component while artificially freezing

every other part of the state would leave the corresponding family used in the proof.

The result gives the theory its organizing quantity: a relative supporting power. It connects the shared field to a definite material state, and that state to clocks, rulers, energy, and motion. Volume makes the size change especially striking: if every linear dimension of a body is halved, its volume becomes one-eighth of the reference volume. A fixed room measured with those smaller rulers would therefore offer eight times the measured volume. That is an invitation to a thought experiment.

A TARDIS for the man cave

Doctor Who's TARDIS is bigger on the inside. Could the material scaling in OQG reproduce that measuring experience? Imagine a box whose interior span is held fixed in exterior reference standards. Assume its occupants and their instruments can enter a corresponding material state with half their exterior linear dimensions. A ruler that spans one metre outside would then span half that exterior distance inside.



"Going out? Think big." Inside, people and furnishings share the local scale; the distant entrance towers above the console room. Conceptual artwork, not a calculated optical view or an engineering design.

On the common branch, size and clock frequency share the same factor, and supporting power scales as its square. Halving the material size therefore requires one-half squared: the interior supporting power must be one-quarter of the exterior reference value. The deficit is 75 percent, or 750,000,000 parts per billion. The exact quadratic relation applies even to this large change. [1]

A span of ten exterior metres would contain twenty of those smaller local metre rulers. Every linear dimension would measure twice as large, and the volume eight times as large, in the interior standards. The clocks would also accumulate cycles at half the exterior reference rate. The change in size comes with a change in time comparison.

Inside, the occupants, furniture, and console can all have ordinary proportions relative to one another. The enclosing span stays fixed in exterior standards, so the smaller occupants measure a larger room. If that span instead shrank with everything inside it, the effect would disappear. The high doorway, receding walls, and flared elevator in the illustration dramatize the scale comparison; the actual view would require calculating how light crosses the transition.

Keep the supporting power uniform throughout the occupied room. Along the entrance route, put the change into a smooth transition, represented here by the staircase and elevator. A visitor descending into the lower-power state shrinks and moves downhill in stored material energy. Slow entry would require controlling the energy released; returning to the exterior requires supplying it again. Once inside, this uniform supporting-power profile supplies no further directional force.

The power theorem sets the equilibrium target; it does not supply a way to build the room. The walls still separate the interior and exterior states, so their boundary response must be included even though occupants cross the transition only at the entrance. What source could sustain that contrast, preserve the enclosing span, and manage the entry and exit energy?

My version of the TARDIS would stay put. I would settle for more room for my stuff in the man cave. At the half-scale setting, my body and clock would run at half the outside rate: one year for me while two passed outside.

More room for my stuff, and less aging while I'm enjoying it.

Gravitational potential energy

Return from the imaginary room to the book. Your arm does work while you lift it. The familiar name for the resulting energy increase is gravitational potential energy. If you lower the book reversibly, that energy can be returned as useful work. A descending weight can drive a mechanism because the lifting left a recoverable difference between the two configurations.

OQG identifies that difference with a change in the body's complete material energy in the source's environment. Moving to another height changes the supporting balance and hence the equilibrium state. The work of lifting supplies the increase in that storage. Lowering permits the stored difference to be recovered. [1]



The lift supplies recoverable work. OQG identifies the corresponding potential-energy change with the adjusted material state.

For a one-kilogram body lifted one metre near Earth's surface, the increase is about 9.8 joules. Those joules are tiny compared with the body's complete rest energy. A very small relative change in a large material energy can therefore account for a familiar amount of mechanical work. The body does not need to look visibly different for its changed state to matter mechanically.

The statement has a defined physical setting: a small complete body compared at different heights in a specified source background. It does not divide the total interacting universe into arbitrary independent pieces, each carrying the same interaction energy again. Mutual interactions require a consistent account of the whole system.

Potential energy also needs a reference. We can choose zero at the floor, at the shelf, or at a distant reference position. The choice changes the labels. The energy difference returned by lowering the book remains the same. OQG's proposed location of the recoverable change in the material state gives that familiar bookkeeping a physical meaning.

Now consider the force. If the equilibrium energy is different at neighboring positions, the body's motion responds to that variation. In elementary mechanics, this is the slope of the potential-energy landscape. OQG obtains that landscape from the material storage. A spatially uniform shift can change the state without supplying a preferred direction of acceleration. A gradient supplies the directional effect.

This is what the image of a gravity well can tell us. Its vertical depth represents a potential-energy comparison. Moving uphill costs work; moving downhill can release it. In OQG the landscape is tied to changed material storage and to the supporting-power profile, meaning how that relative power varies with position.

The familiar inverse-square pull also has a precise place in this picture. An interaction energy varying inversely with distance has a slope that varies inversely with distance squared. At twice the distance, the leading pull is one quarter as large. A field amplitude, received power, interaction energy, and force are different quantities; their distance laws cannot simply be substituted for one another. The OQG construction connects the appropriate conservative interaction energy to storage before calculating the force. [1]

Why do bodies of different composition fall together? A larger force need not mean a larger acceleration; inertia matters too. OQG derives both from the same relation between complete material energy and momentum. For bodies satisfying its linked energy and inertia scaling, the dependence on the amount of matter cancels from the leading free-fall acceleration. Composition tests check whether this correspondence holds for different complete bodies. [1]

The calibrated Earth example makes the connection quantitative. Matching the gravitational strength to its measured reference value gives a supporting-power deficit at Earth's surface of approximately 1.39 parts per billion relative to the specified distant reference. On the common branch, the clock-frequency and material-size deficits are approximately half that fraction, in the same reference standards. Their variation with height yields consistent lifting work and acceleration. [1]

This is a fractional inference through the proved correspondence, not a separate measurement of the nuclear supporting exchange in watts. It tells us how the clock, power, and work comparisons must agree under the same calibration. The very small number explains why everyday matter can remain recognizably itself while participating in the response we call gravity.

The fabric of spacetime

Every statement about distance and duration eventually refers to a physical comparison. A ruler compares a length with a material standard. An atomic clock compares elapsed evolution with a repeatable transition. A light signal connects events and allows distant measurements to be related. An observer is therefore part of the physical account.

Suppose the states realized at two locations differ. Their clocks need not accumulate the same number of cycles between the events used for comparison. Their rulers need not represent the same lengths in a common reference description. The propagation of signals between them must also be included. Geometry is a compact way to express all of these comparisons together.

The metric is the mathematical rule that performs this job locally: it relates coordinate differences to the durations and distances assigned by the physical standards. A coordinate is an address in a description. Proper time is the duration accumulated by a clock along its actual history. These are familiar ideas once the measuring devices stay in view.

When we say that gravity slows time, the measurable statement is that appropriately compared clocks accumulate different durations. OQG supplies a material account of the clock-rate change through the altered equilibrium and transition frequencies. A clock beside you does not feel defective. Your nearby reference processes belong to the same local conditions. The difference appears when physical histories or separated standards are compared. [1]



Compare the clocks, not an invisible flow of time. The higher clock accumulates time slightly faster; the difference is not shown to scale.

This is a real experimental effect. Atomic-clock experiments have resolved gravitational frequency differences across a millimetre-scale sample. Such observations establish the clock comparison with extraordinary precision; an alternative microscopic interpretation must reproduce it. They do not, by themselves, choose between explanations that predict the same comparison. [4]

The same discipline applies to the speed of light. OQG relates electromagnetic coefficients, clock rates, and ruler scales in declared comparison standards. A speed expressed using one reference set of clocks and rulers can change between states while a local measurement, made with the accompanying local standards, retains the same limiting value. The measuring apparatus participates in the conversion. This should not be read as the claim that a nearby observer simply watches vacuum light behave like light in an ordinary piece of glass. [1]

This is also why the construction is more than changing the names of units. Renaming a metre does not alter a clock comparison, a returned signal, or the relative motion of two bodies. OQG relates different physical states and their dimensionless comparisons. Where a uniform common change cancels from a strictly local comparison, that comparison cannot reveal it. Where clocks, signals, or trajectories compare different conditions, measurable differences remain.

What, then, is a straight path? In everyday language it is the route of an object that is not being steered. In relativity the corresponding free trajectory is called a geodesic. It can look curved on a spatial map because the full comparison involves time as well as space, and because the comparison rules vary with position.

OQG derives the free trajectory from the body's material energy and momentum relation. Its Hamiltonian, the energy expressed in terms of position and momentum, governs how the body moves. In a smooth, slowly varying environment, the calculated matter-wave paths satisfy the geodesic equation of the corresponding metric. The material and geometric descriptions give two accounts of one trajectory, with the interaction counted once. [1]

This resolves the apparent disagreement between a falling body gaining speed and its accelerometer reading zero. An accelerometer detects the load between an internal test mass and its casing. On the table, the book is supported against free fall. Once released, the ideal small instrument and its test mass fall together, leaving no support load to register. A distant observer can still record changing position and velocity. The two measurements answer different questions. [1]

An orbit is the same familiar fall carried around a planet. The orbiting body keeps falling while its sideways motion carries it around the source. In OQG, the material dynamics determine that freely evolving path, and geometry expresses it as a geodesic. Weightlessness in an orbiting laboratory is part of the gravitational account.



Both the dropped book and the orbital laboratory are in free fall. A changing trajectory and a zero accelerometer reading describe different measurements.

Curvature becomes clearest when we compare neighboring freely falling bodies. They can approach, separate, or accelerate relative to one another in different directions. These are tidal effects. Coordinates that fall with one sufficiently small laboratory remove its local gravitational acceleration from the coordinate description; they do not remove the relative motion across an extended region. [1, 5]

In the OQG account, tides reflect spatial variation in the energy gradient and the associated clock and ruler comparisons. In the geometric account, spacetime curvature expresses these relationships. Curvature therefore has physical content even when we decline to imagine a sheet bending into some unseen surrounding room. The cloth picture has reached its limit; the comparisons have not.

Light belongs in the same account. Its propagation is compared by the clocks and rulers established in the field and matter environment. The geometrical description predicts the paths of light, including bending and travel-time effects. A complete material realization must reproduce that propagation as well as the motion of massive bodies. Changing only a massive test object's energy would not, on its own, finish the light-bending problem.

The next target is the Schwarzschild exterior, the familiar vacuum geometry around an isolated, uncharged, nonrotating spherical source. OQG reconstructs it by allowing the clock and ruler factors to differ and specifying two additional conditions: the exact supporting-power profile and the radial ruler response, meaning how radial distances are compared. These conditions connect the material account to the chosen vacuum solution of Einstein's equations. They are inputs beyond the leading scattering example. [1]

The reader can now return to the phrase curved spacetime with a more concrete picture. Matter changes the shared response. That response changes material equilibrium, storage, and physical standards. Those standards, together with signal propagation and free motion, establish the relationships expressed by the metric. The curvature tells us how the relationships vary across a region.

One final distinction helps with the word covariance. General covariance concerns the independence of the physical description from the coordinates chosen to label events. The coordinated material scaling used in OQG concerns relations between physical states. Changing the map labels and changing the system being mapped are different operations. The theory needs to keep both accounts consistent.

Ripples in spacetime

So far, the book has led us through a stationary gravitational environment. A traveling disturbance adds a new question: how does the response carry energy and momentum from one region to another?

This is the setting behind the familiar phrase ripples in spacetime.

Gravitational-wave detectors compare carefully controlled light paths and test-mass motions. A passing wave changes those comparisons. The Laser Interferometer Gravitational-Wave Observatory, or LIGO, describes this pattern as a ripple in spacetime. The measurement establishes a propagating gravitational effect; its microscopic explanation remains a further question. [8]



Artist's view of a traveling gravitational disturbance reaching Earth. Detectors measure changing light paths and test-mass motion; the painted ripples are illustrative.

Operational Quantum Gravity: From Standard Model Stress Response to Gravity-Induced Entanglement develops the causal stress response of quantum matter: how the interacting system responds after a disturbance. Here stress response includes energy and momentum flow, pressure, and shear, the distortion that changes shape. The calculation follows those quantities for the complete interacting matter and fields. [7]

The system can resist deformation, store energy, dissipate it into other channels, or propagate a disturbance. Its response spectrum describes how these behaviors depend on frequency. Stiffness describes resistance to a change; compliance describes how much the system yields. Both belong to the response of matter and fields.

On the stated long-wavelength branch, where wavelengths are large compared with the microscopic response scales, OQG represents this quantum response in Einstein-equivalent form. It has the two gravitational-wave polarizations, the independent patterns of stretching and squeezing across the direction of travel. Their propagation and damping must follow from the time-dependent response; a static inverse-distance potential alone cannot establish them. [1, 7]

This does not identify a gravitational wave with an ordinary light wave. The proposed gravitational response involves the collective, direction-dependent stress of the complete system. An electromagnetic excitation and a gravitational excitation describe different patterns of that system's behavior. Their relationship has to follow from the response calculation.

In a quantized description, a graviton would be a quantum of the gravitational excitation. OQG's claim is that quantum matter supplies a response whose large-scale representation has the required gravitational form. Quantizing that collective description does not, by itself, justify adding a second independent interaction of the same strength.

Energy and momentum still matter. A traveling disturbance can exchange them with a detector. Causality still matters too: the response follows the disturbance through the causal propagation law. A metaphor about stretching time does not give a laboratory permission to send a controlled message before it is sent.

The physical account now includes exchange, interference, reversible storage, and traveling disturbances. The response spectrum describes how the coupled matter and fields behave. Geometry records the resulting comparisons and motions.

From the book to the cosmos

The same material viewpoint leads to questions with familiar names: the vacuum catastrophe, dark energy, dark matter, and the black hole singularity. Companion manuscripts address these problems and gravitational entanglement, each with its own assumptions and derivations. Their results include an exact statement about the energy zero, a fitted cosmic history, galaxy-response reconstructions, a restriction on allowed material states, and a calculation of gravitational entanglement. [6, 7, 12]

The vacuum catastrophe

The vacuum catastrophe is the enormous mismatch between straightforward estimates of quantum vacuum energy and the much smaller cosmological gravitational effect inferred from observation. OQG begins by separating an arbitrary common energy offset from a physical change of state, a stress, or a

measurable field response. The question is which of these can actually change gravity.

Operational Quantum Gravity: Four Consequences of a Matter-First Response holds fixed the mathematical measure, the rule that weights spacetime regions in the response calculation. With that rule and the physical preparation unchanged, shifting the common energy-density zero leaves the local response unchanged. This exact invariance removes that arbitrary reference offset as a local gravitational source. It does not require repeatedly adjusting two huge contributions to cancel one another. [6, 7]

Actual vacuum physics remains. Boundary-dependent forces, polarization, fluctuations, and changes of state can still affect matter. A reference zero and a physical stress have different roles. The theorem leaves the cosmological constant in the large-scale gravitational equations to be specified; it does not calculate that constant's observed value.

Dark energy and cosmic expansion

Dark energy is the name given to the component used in standard cosmology to account for the accelerating expansion of the universe. Its relation to vacuum energy makes the previous question consequential. We receive light emitted when the universe was younger and compare it with material standards realized today. A redshift is an observed frequency comparison. Its interpretation connects emission, propagation, reception, and the history of those standards.

OQG develops a cosmological comparison in which material clock and ruler scales evolve with the background state. In the model studied, the cosmological constant is set to zero, and a fitted history of those standards reproduces the inferred cosmic acceleration without a physical dark energy fluid. The proposed mechanism is a changing availability of the energy that supports the material states. Total energy remains conserved while irreversible processes change the portion available to sustain the earlier state. [6]



The dark energy question begins with distant light and present clocks and rulers. OQG examines how the history of those material standards enters the cosmic comparison.

The cosmological calculation fits a two-parameter history to 32 cosmic chronometer measurements, which infer cosmic expansion from the age differences of galaxy populations. It then compares that history with six distance-ratio measurements from the Dark Energy Spectroscopic Instrument, or DESI, without refitting the parameters. The comparison is reproducible but exploratory: the model's form was selected after inspecting high-redshift behavior, and the calculation uses a fixed present-day expansion rate and simplified measurement errors. A fuller statistical analysis, early-universe and structure observations, and a calculation of the microscopic rate are further tests of the account. [6]

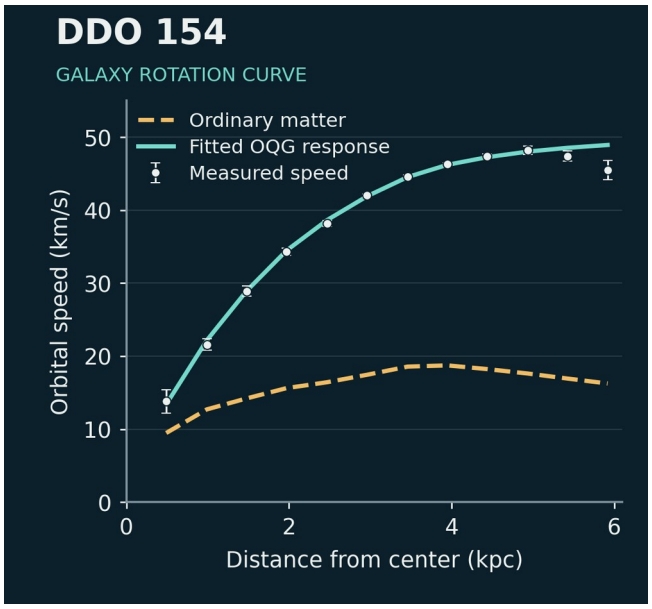
This use of evolving standards is also different from claiming that every stationary gravitational field continuously runs down. A settled spatial variation can be conservative. The cosmological argument concerns an irreversible history of the background state. Mixing the two would confuse the recoverable work of lowering a weight with a changing cosmic supply of available energy.

Dark matter and galaxy rotation curves

Dark matter concerns the extra gravitating matter inferred, under the standard gravitational account, from motions and other observations that ordinary matter alone does not explain. A galaxy rotation curve plots orbital speed against distance from the center. In many galaxies, the measured speeds remain higher than the ordinary-matter contribution predicts. The DDO 154 example shows that gap directly.

Within a chosen OQG branch, the rotation curve can be translated into a supporting-power profile. *Available Power and Collective Scattering in Galactic Rotation*

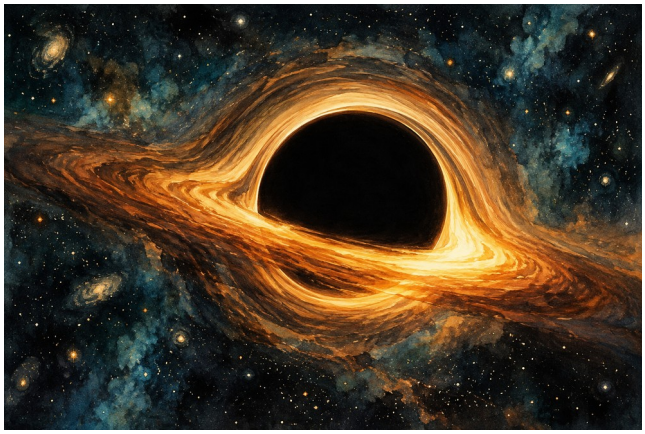
Curves tests a prescribed response profile fitted to the observed speeds. Its DDO 154 fit follows the measurements shown here. The microscopic task is to predict that response from the distribution, composition, and collective scattering of ordinary matter, including its absolute strength. A fitted curve supplies a target for that calculation; it does not by itself resolve the dark matter problem. [12]



DDO 154: measured orbital speeds, the ordinary-matter contribution, and a fitted OQG response. One kiloparsec (kpc) is about 3,260 light-years. The fitted profile is a calculation target, not an independent microscopic prediction. Data: SPARC; response model: Desiato, Available Power and Collective Scattering in Galactic Rotation Curves. [12]

The black hole singularity

The black hole singularity problem concerns the breakdown of the classical description deep inside a black hole. In the familiar spherical solution, curvature grows without bound toward the center. This differs from the event horizon, the boundary beyond which signals cannot reach distant observers. OQG asks what quantum state matter could actually occupy at a proposed zero-size endpoint.



An event horizon limits which signals can escape. The black hole singularity question concerns what happens to matter deeper inside.

The related phrase time stops at the horizon also needs its observer attached. In the familiar stationary black-hole description, signals from an approaching clock become increasingly redshifted and delayed for a distant observer. That does not mean the falling clock locally watches its own mechanism stop. The horizon is a causal boundary, not a place where every physical process must become an unmoving picture. OQG's exterior correspondence preserves the need to distinguish distant comparison time from the proper time of the falling system.

The material-state theorem measures size by the spread of internal positions in a quantum state. In the specified family of normalized states with finite position spreads, the theorem excludes exactly zero extension. Finite changes of scale preserve positive size and the quantum relation between position and momentum. Arbitrarily small positive sizes remain possible; no universal minimum radius is inserted. [6]

Following the state as the load increases also requires the accumulated scale response to remain finite over every finite loading interval, with a valid material state available throughout. At extreme density, phase changes or changes in the response could affect those conditions. Excluding the exact pointlike state in this family does not by itself establish every possible infall history or complete a model of the black-hole interior.

The physical question is now sharper. When a geometric description reaches a boundary, what quantum state could the matter actually occupy there? A boundary in a classical spacetime model does not, by itself, specify a physically realizable quantum state of matter. Horizons remain meaningful while the fate of the material is addressed through its allowed quantum states.

Quantum entanglement

Finally, consider the suggestion that entangled objects must be joined by a wormhole. Entanglement means that the combined quantum state cannot be built as a statistical mixture of separate states for the individual parts. A proposed tunnel is an additional interpretation, and the experiment has to tell us what is actually required.

OQG's response, completed to respect energy and momentum conservation, produces the coherent gravitational phase in the standard two-body entanglement proposal under its specified conditions. Phase describes the progression of a quantum wave; relative phases track differences between the alternative paths. The interaction can entangle the bodies without adding an Einstein–Rosen bridge, a spacetime tunnel, between them. The quantum-matter response supplies a realization of the same phase. [6, 7]

An entanglement witness is a measurement that establishes entanglement. In the proposed controlled experiment, with other interactions accounted for, it would test the nonclassical character of the effective gravitational interaction under the protocol's assumptions. A shared phase prediction would not select OQG uniquely. Noise, propagation delays, and more detailed correlations offer further questions beyond that phase; entanglement itself does not enable controlled faster-than-light messages.

These examples follow one order of explanation: identify the prepared matter and its response, calculate the observable comparison, then find the geometric description that represents it. Each picture leads back to a physical question.

What the connection accomplishes

OQG connects electromagnetic exchange and quantum matter's response to gravitational potential energy, clocks, rulers, and free fall. Its proposed mechanism underlies the comparisons that geometry records.

The scaling theorems link stable binding, nuclear response, recoverable energy, and the Hamiltonian governing motion within the stated corresponding family. [1]

The construction retains strong-interaction binding and complete material energy and stress. It does not reduce every interaction to an ordinary electric force. [1]

For an engineer, the questions are concrete: what sustains the required material state, how are energy and momentum exchanged, and what would instruments measure? A drawn warp bubble supplies no controller.

An isolated ship needs external momentum exchange to accelerate its center of mass. Internal stress changes alone cannot provide it. Reduced energy density is not negative total energy. *Warp Drive Constraints, Gravitational Energy Storage, and a Proposed Proper-Time-Matched Flight Experiment* applies the weak-field correspondence to a specified flight and measurement protocol, without claiming demonstrated gravity-control technology. [9]

Operational Quantum Gravity: From Electromagnetic Power Balance to Gravitational Response calibrates absolute strength to measured gravity and specifies the spherical response conditions. Predicting that strength from the constituent response remains the microscopic task; the proved scaling relationships are fixed. [1]

The next target is a supporting-power profile calculated from the collective nuclear response, including consistent field and material adjustment. Does it reproduce the profile inferred from clocks and gravitational motion, including absolute strength? That would test the mechanism beyond calibration. [1]

Where OQG and general relativity predict identical observables, measurements cannot distinguish their interpretations. A distinguishing experiment needs a measurable, quantified difference beyond the demonstrated equivalence. That prediction remains an open task. [1]

Return to the book on the shelf. In OQG's account, even that still object participates in an electromagnetic exchange with its surroundings.



Back to the book. Field exchange, stored energy, physical standards, and motion meet in one familiar object.

Lifting changes stored energy; falling reveals its gradient. Clocks and rulers track the motion. In OQG, the fabric of spacetime records those material comparisons.

Matter tells matter how to scale. Geometry is just bookkeeping.

Sources and further reading

The principal source is *Operational Quantum Gravity: From Electromagnetic Power Balance to Gravitational Response* [1]. The wider results draw on the other OQG studies listed below. Entries 10 and 11 supplied audience questions and terminology. The conceptual illustrations are AI-generated artwork. The DDO 154 figure uses the numerical data and fitted response accompanying *Available Power and Collective Scattering in Galactic Rotation Curves* [12].

[1] Desiato, T. J. *Operational Quantum Gravity: From Electromagnetic Power Balance to Gravitational Response*. October 2026. Preprint submitted to Classical and Quantum Gravity. Source for the supporting-power theorem, nuclear storage, stable scaling, recoverable work, geodesic motion, calibrated Earth comparison, and conditional Schwarzschild reconstruction. Full text on Academia; Author's ResearchGate publications.

[2] Luis-Hita, J., and colleagues. "Light Induced Inverse-Square Law Interactions between Nanoparticles: 'Mock Gravity' at the Nanoscale." Physical Review Letters 123, 143201 (2019). Electromagnetic scattering mechanism benchmark. Research article

[3] Rahi, S. J., Emig, T., Graham, N., Jaffe, R. L., and Kardar, M. "Scattering Theory Approach to Electrodynamic Casimir Forces." Physical Review D 80, 085021 (2009). Research paper

[4] Bothwell, T., and colleagues. "Resolving the gravitational redshift across a millimetre-scale atomic sample." Nature (2022). NIST publication record and primary research: NIST publication record; Research article

[5] Einstein Online, Max Planck Institute for Gravitational Physics. "Gravity: From weightlessness to curvature." An accessible explanation of free fall and tidal effects. Einstein Online

[6] Desiato, T. J. *Operational Quantum Gravity: Four Consequences of a Matter-First Response*. Manuscript dated 27 September 2026. Source for the exact identity-shift result, fitted cosmological reconstruction, conditional positive-extension result, and coherent gravitational entangling phase.

[7] Desiato, T. J. *Operational Quantum Gravity: From Standard Model Stress Response to Gravity-Induced Entanglement*. Version 0.5, 2026. Used together with entry 6 for the causal collective response and its stated macroscopic branch.

[8] LIGO Laboratory. "What are Gravitational Waves?" Public explanation of gravitational-wave propagation and detection. LIGO Laboratory

[9] Desiato, T. J. *Warp Drive Constraints, Gravitational Energy Storage, and a Proposed Proper-Time-Matched Flight Experiment*. Version 1.2, 2026. Engineering companion manuscript.

[10] World Science Festival. "Coming to Grips With Gravity." Public panel, 4 June 2016. Audience context for the distinction between successful gravitational predictions and questions about physical explanation. Panel recording and transcript

[11] Physics Stack Exchange. "The Fabric of Space-time?" and "The 'fabric' of space is what exactly?" Public discussion threads consulted for reader questions about a literal fabric and light following curved space. First discussion; Second discussion

[12] Desiato, T. J. *Available Power and Collective Scattering in Galactic Rotation Curves*. 13 October 2026, with numerical reproducibility package. DDO 154 measurements and ordinary-matter components: Lelli, F., McGaugh, S. S., and Schombert, J. M., *SPARC: Mass Models for 175 Disk Galaxies with Spitzer Photometry and Accurate Rotation Curves*, Astronomical Journal 152, 157 (2016), doi:10.3847/0004-6256/152/6/157. The illustrated response fit uses the prescribed turnover radius of ten times the last measured radius.