

Experimental Protocol for Verifying the Fundamental Yield Threshold of Physical Vacuum

Abstract

We propose an experimental protocol for the direct laboratory test of the hypothesis of a fundamental yield threshold of the physical vacuum — a critical value of gravitational self-energy $E_{\text{max}} \approx 2.05 \times 10^{-32}$ J, at which the reversible geometric deformation of spacetime (GR metric) abruptly transitions into irreversible plastic dissipation. The protocol relies on ringdown measurements of the center-of-mass oscillations of levitated fused silica (SiO_2) microspheres in an optical tweezer at cryogenic temperatures. The primary marker of the transition is a discontinuous drop of the quantum contrast V of the interference pattern. A precision scanning grid of eight steps in the diameter range 1.0–5.0 μm is constructed, with the critical point $D_{\text{crit}} = 2.863 \mu\text{m}$ and the critical mass $M_{\text{crit}} = 27.04 \text{ pg}$. Rigorous mathematical criteria for confirmation and falsification are formulated, including a temperature-invariance test and cross-material scaling. The model is falsifiable: the predicted discontinuity in $V(M)$ is experimentally distinguishable from the smooth monotonic decay expected in thresholdless collapse models (GRW, CSL, Diósi–Penrose).

Keywords: vacuum yield threshold, induced gravity, substantial time, quantum decoherence, optomechanics, optical tweezer, ringdown, objective reduction, Prigogine bifurcation, falsifiability.

1. Introduction

Modern theoretical physics lacks an experimentally verifiable criterion for the transition from the quantum to the classical regime. General Relativity (GR) describes the reversible geometric deformation of spacetime but does not set limits on the validity of this elastic approximation. Quantum Field Theory (QFT) postulates infinite vacuum elasticity, which leads to the cosmological constant problem (a discrepancy of 120 orders of magnitude) and unresolved singularities in gravitational collapse.

1.1. Theoretical Foundations of the Model

The model rests on three pillars.

1. Sakharov's induced gravity. The physical vacuum is treated as an elastic medium with a bulk modulus $K_{\text{vac}} = c^4/(16\pi G) \approx 2.41 \times 10^{42} \text{ Pa}$. Gravity is an emergent effect of the elasticity of quantum vacuum fluctuations [3]. However, Sakharov did not pose the question: what happens when the elastic limit is exhausted? From continuum mechanics it is known: upon exceeding the yield limit, elastic deformation gives way to plastic flow, and reversible energy storage becomes irreversible dissipation.
2. Prigogine's bifurcation. Irreversibility does not emerge gradually but via a discrete jump — a bifurcation — where reversible (unitary) evolution is replaced by irreversible dynamics [6]. In our model, this is the point where the elastic deformation of the vacuum abruptly transitions to plastic flow.
3. Levich's substantial time. Below the threshold, time is an external parameter in the Schrödinger equation. At the bifurcation point, dissipation of the substance flux begins — time becomes a physical process, and the arrow of time is born [7].

Key postulate: The physical vacuum possesses a yield threshold E_{max} — a critical energy at which the elastic regime abruptly yields to plastic dissipation. The gravitational self-energy of

a massive body EG accumulates as the energy of elastic deformation of the vacuum. When $E_G = E_{\max}$, an instantaneous rupture of the coherence of the center-of-mass quantum superposition occurs objectively, without an external observer.

Derivation of $E_{\max}$

The phenomenological yield threshold $E_{\max}$ is derived from fundamental constants ($\hbar$, c , G) and the cosmological constant (Λ).

The Planck energy: $E_P = \sqrt{(\hbar c^5/G)} \approx 1.956 \times 10^9$ J.

The energy of the intrinsic pre-stress of the vacuum contained in the Planck volume: $E\Lambda = \rho_{\text{vac}} \times V_P = (\Lambda c^4/(8\pi G)) \times I_P^3$, where $I_P = \sqrt{(\hbar G/c^3)}$ is the Planck length, $\Lambda \approx 1.1 \times 10^{-52} \text{ m}^{-2}$.

Numerical values: $\rho_{\text{vac}} = \Lambda c^4/(8\pi G) \approx 5.30 \times 10^{-10} \text{ J/m}^3$, $V_P = I_P^3 \approx 4.22 \times 10^{-105} \text{ m}^3$, $E\Lambda \approx 2.24 \times 10^{-114} \text{ J}$.

The dimensionless ratio $\Lambda P = E\Lambda/E_P$ is interpreted as the volume fraction of excited vacuum bonds. In 3D space, this volume fraction transforms into linear strain via the cubic root: $\epsilon_{\text{crit}} = (E\Lambda/E_P)^{1/3}$.

The critical energy threshold: $E_{\max} = E_P \times \epsilon_{\text{crit}} = (E_P^2 \times E\Lambda)^{1/3} \approx 2.05 \times 10^{-32} \text{ J}$.

The exponent 1/3 is forced by the dimensionality of space: in d -dimensional space $(E_{\max})^d = (E_P)^{d-1} \times E\Lambda$. The algebraic self-consistency of the model holds exclusively at $d = 3$.

The derivation of $E_{\max}$ is phenomenological: dimensional analysis uniquely fixes the combination $E_{\max} = E_P \times (E\Lambda/E_P)^{1/3}$ from the available energy scales, consistent with the continuum-mechanics analogy where the yield stress is linearly proportional to the yield strain through the elastic modulus. The precise numerical value is a prediction to be tested experimentally, not a result derived from first principles.

Characteristic scales:

Reduction time: $\tau = \hbar/E_{\max} \approx 5.16 \text{ ms}$ Vacuum angular frequency: $\omega_{\text{vac}} = E_{\max}/\hbar \approx 194.0 \text{ rad/s}$ Linear frequency: $f_{\text{vac}} = E_{\max}/h \approx 30.9 \text{ Hz}$

This work translates the hypothesis from theoretical metaphysics into the realm of direct high-precision laboratory experimentation. The protocol is fully adapted to the standard toolkit of modern quantum optomechanics [8] and requires no fundamentally new equipment. Recent advances in cooling levitated nanoparticles to the quantum ground state provide the technical basis for this experiment.

2. Experimental Setup

The protocol is fully compatible with the standard infrastructure of modern quantum optomechanics [8].

Target: Isolated spheres of ultra-pure fused silica (SiO_2 , $\rho = 2.2 \text{ g/cm}^3$) with diameter D from 1.0 to 10.0 μm .

Trap: Single- or dual-beam optical tweezer ($\lambda = 1064$ nm, power tunable in the range 10–100 mW). Nominal frequency of center-of-mass mechanical modes in the trap $f_0 = 50$ –150 kHz.

Environment: Deep cryogenic vacuum ($P \leq 10^{-6}$ mbar, base temperature $T = 4$ K with controlled heating up to 100 K). Active feedback cooling is used to cool the measured center-of-mass mode to the quantum limit.

Detection: Back-focal-plane interferometry with signal registration on balanced photodiodes.

3. Measurement Protocol

1. A SiO₂ microsphere is held in an optical trap, cooled by feedback cooling to cryogenic temperature (≤ 4 K) at pressure $P \leq 10^{-6}$ mbar.
2. A short coherent pulse is applied to the center-of-mass mechanical mode, placing the microsphere into a state of spatial separation (quantum superposition).
3. After the pulse ends, the free decay (ringdown) is recorded by the interferometer in the back focal plane using balanced photodiodes. The measured quantity is the contrast of the interference pattern $V(t)$.
4. The mass of each individual sphere is verified in situ by the shift of the trap frequency $f_0 = (1/2\pi)\sqrt{(k/M)}$ at calibrated stiffness k and cross-confirmed by SEM images. Allowable discrepancy $\leq 5\%$.

Primary measured variables:

$V(M)$ — the contrast of interference fringes as a function of the sphere's mass M (or diameter D), measured at a fixed time after the pulse termination. This function is used to detect a discontinuity (jump) at the threshold.

$V(t)$ — the contrast of interference fringes as a function of time for a fixed mass. This characterizes the temporal rate of coherence decay.

The gravitational self-energy of a homogeneous sphere with density ρ and diameter D : $E_G = (\pi^2/30) \times G \times \rho^2 \times D^5$.

Equating $E_G = E_{\max}$ yields the critical diameter: $D_{\text{crit}} = ((30 \times E_{\max})/(\pi^2 \times G \times \rho^2))^{(1/5)}$.

The critical mass: $M_{\text{crit}} = (\pi/6) \times D_{\text{crit}}^3 \times \rho$.

CODATA-based recalculation: **$D_{\text{crit}} = 2.863 \mu\text{m}$, $M_{\text{crit}} = 27.04 \text{ pg}$.**

Below the threshold — the "silence zone": the vacuum deforms strictly elastically, dissipation is absent, decoherence is zero. At the threshold — an instantaneous rupture of coherence (bifurcation). Above the threshold — plastic flow of the vacuum, dissipation rate: $\Gamma_c = \omega_{\text{vac}} \times (E_G/E_{\max}) \times (E_G/E_{\max} - 1)$.

4. Scanning Grid

A precision scanning grid in the vicinity of the discontinuity. Values of $E_G/E_{\max}$ are strictly aligned with the fifth power of the diameter D^5 . $D_{\text{crit}} = 2.863 \mu\text{m}$, $M_{\text{crit}} = 27.04 \text{ pg}$.

Coarse pass: $V(t)$ at diameters 1, 3, 5, 7, 10 μm . Refinement: fine step $\Delta D \sim 0.13\text{--}0.20 \mu\text{m}$ in the vicinity of the discontinuity ($2.70 \rightarrow 2.863 \rightarrow 3.00 \rightarrow 3.20 \mu\text{m}$). Temperature control: series at 4 K and ~ 100 K.

Table. Precision scanning grid of the discontinuity

Step | D, μm | M, pg | EG/E_{max} | Behavior of $V(t)$ during ringdown | Physical status

No. 1 | 1.00 | 1.15 | 0.0052 | Stable ringdown, damping strictly by classical friction | Deep sub-threshold

No. 2 | 2.00 | 9.22 | 0.1664 | Ringdown stable. Quartz defects give smooth linear background | Sub-threshold

No. 3 | 2.50 | 18.0 | 0.5077 | Pre-threshold. Maximum fringe contrast. Boundary of "silence zone" | Quantum control point

No. 4 | 2.70 | 22.7 | 0.7460 | Ringdown retains full quantum visibility of fringes | Threshold fixation step -6%

No. 5 | 2.863 | 27.04 | 1.0000 | DISCONTINUITY POINT. Instantaneous drop of contrast $V \rightarrow 0$ within $\tau \approx 5.16$ ms | CRITICAL YIELD THRESHOLD

No. 6 | 3.00 | 31.1 | 1.2630 | Complete absence of coherent response from $t = 0$ | Threshold fixation step $+5\%$

No. 7 | 3.20 | 37.7 | 1.7444 | Suprathreshold regime of plastic flow. Quantum response impossible | Suprathreshold

No. 8 | 5.00 | 144.0 | 16.246 | Deep macroscopic classical regime. Effect "was and never became" completed | Classical control point

The proposed protocol allows experimental distinction between the threshold model and thresholdless collapse models (GRW, CSL, Diósi–Penrose) by four independent criteria: (1) presence of a "silence zone" at small D, (2) sharp discontinuity of $V(M)$ at M_{crit} , (3) temperature invariance of the threshold position, (4) scaling of the threshold with density $\rho^{-2/5}$ [1, 2, 4, 5].

Additional macroscopic evidence: Extrapolation to scale $D = 10.0 \mu\text{m}$ ($M = 1152$ pg, $EG/E_{\text{max}} \approx 520$) predicts a catastrophic drop in mechanical quality factor Q_m by $\sim 98\%$, while the decay time shrinks from 3.18 s to 0.064 s. This demonstrates the activation of a powerful non-local volumetric dissipation channel (deformation heating of the elastoplastic vacuum).

5. Mathematical Criterion of Validity and Falsifiability

The main barrier to model acceptance is the final exclusion of materials science artifacts and instrumental systematic effects. Physics of defects such as two-level systems (TLS) in fused silica, lattice defects, and residual gas fluctuations are strictly limited to generating smooth, continuous decay functions with a continuous first derivative. Landauer's information-theoretic concept of irreversibility [9] provides an additional perspective on fundamental dissipation limits in physical systems.

5.1. Mathematical Criterion of Discontinuity

Strict experimental proof of the fundamental yield threshold of spacetime is a jump-discontinuity of the contrast function $V(M)$ at the critical point $M_{\text{crit}} = 27.04 \text{ pg}$:

— For $M < M_{\text{crit}}$: $V(M)$ remains constant (stable quantum coherence, "silence zone"), with no monotonic dependence on mass. — For $M \geq M_{\text{crit}}$: $V(M) = 0$ (complete loss of coherent response).

At $M = M_{\text{crit}}$, the function $V(M)$ undergoes a first-kind discontinuity (finite jump). The first derivative dV/dM does not exist at this point:

$$\lim(M \rightarrow M_{\text{crit}}^-) dV/dM \approx 0, \lim(M \rightarrow M_{\text{crit}}^+) dV/dM = -\infty.$$

This signature is mathematically distinct from the smooth, monotonic decay predicted by thresholdless collapse models [1, 2, 4, 5] and from any known materials-science artifact. The temporal evolution satisfies $\tau = \hbar/E_{\text{max}} \approx 5.16 \text{ ms}$; at $M > M_{\text{crit}}$, $V(t) = 0$ from $t = 0$.

5.2. Confirmation Criteria (Threshold detected if)

1. Flat silence zone: The curve $V(M)$ remains perfectly flat in the diameter interval $1.0\text{--}2.5 \text{ }\mu\text{m}$.
2. Jump-discontinuity: A sharp jump of $V(M)$ from 1 to 0 is registered exactly at diameter $D = 2.863 \text{ }\mu\text{m}$ and mass $M_{\text{crit}} = 27.04 \text{ pg}$ at cryogenic temperature (4 K).
3. Temperature invariance of the discontinuity: The position of the discontinuity point ($D = 2.863 \text{ }\mu\text{m}$, $M_{\text{crit}} = 27.04 \text{ pg}$) must remain strictly unchanged when heating the thermal bath from 4 K to 100 K. Any thermal shift of the discontinuity point would reveal classical thermally activated defect dynamics in the solid (where Q_m typically scales as $1/T$), immediately falsifying the quantum-gravitational interpretation.
4. Reproducibility across different particles: The result is reproduced on multiple independent microspheres.
5. Geometric scaling (cross-material test): Upon replacing the sphere material (e.g., with diamond, $\rho = 3.5 \text{ g/cm}^3$, or silicon, $\rho = 2.33 \text{ g/cm}^3$), the discontinuity coordinate must shift in strict accordance with the geometry of gravitational self-energy: $D_{\text{crit}} \propto \rho^{-2/5}$.

5.3. Falsification Criteria (Model refuted if)

1. The contrast function $V(M)$ exhibits a smooth, continuous, and monotonic decrease across the entire scanning spectrum from 1.0 to $10.0 \text{ }\mu\text{m}$ without a jump-discontinuity and without a recognizable "silence zone". This result would confirm standard background noise models or thresholdless collapse theories.
2. The position of the discontinuity shifts with temperature — thermal activation rather than a fundamental threshold.
3. $V(M)$ exhibits a smooth monotonic decrease starting from the smallest diameters, without a "silence zone" — consistent with thresholdless models (GRW, CSL, Diósi–Penrose) [1, 2, 4, 5].

Thermal systematic suspected if: the quality factor scales as $Q_m \propto 1/T$ — a classically thermally activated mechanism rather than a fundamental threshold of spacetime.

5.4. Separation from Alternative Models

The presence of a flat "silence zone" ($V \approx 1$) at small diameters followed by a sharp discontinuity allows experimental falsification of thresholdless spontaneous collapse models [1, 2, 4, 5], which predict a monotonic smooth decrease of coherence from the smallest values of mass.

6. Conclusion and Theoretical Implications

The proposed optomechanical protocol translates the hypothesis of the yield threshold of the physical vacuum from theoretical metaphysics to the realm of direct high-precision laboratory experimentation. The key prediction — a discontinuous, stepwise character of the contrast function $V(M)$ with a flat "silence zone" below the threshold and a complete collapse of coherence above it — is experimentally distinguishable from the smooth monotonic decrease expected from all known materials science noises and thresholdless collapse models. Four independent criteria — flat zone, jump at D_{crit} , temperature invariance, and cross-material scaling — ensure a rigorous separation of a fundamental gravitational yield threshold from instrumental artifacts.

The experiment requires no fundamentally new equipment and can be implemented on the existing infrastructure of laboratories working with cooling levitated nanoparticles to the quantum ground state [8]. A positive result — registration of a discontinuity at $D = 2.863 \mu\text{m}$ and $M_{\text{crit}} = 27.04 \text{ pg}$ — would experimentally confirm the existence of a fundamental yield threshold of the physical vacuum.

A positive experimental result — the registration of a discontinuous, stepwise drop of the quantum contrast V at the critical point $D_{\text{crit}} = 2.863 \mu\text{m}$ ($M_{\text{crit}} = 27.04 \text{ pg}$), invariant under temperature variation and consistent with cross-material scaling — would carry consequences across several domains of theoretical physics.

6.1. The Quantum-Classical Transition and the Bohr–Einstein Debate

The yield threshold would provide the first quantitative, experimentally reproducible criterion for the boundary between the quantum and classical regimes. The transition is not a smooth decoherence gradient, but a discrete bifurcation driven by gravitational self-energy.

This reframes the century-long debate between Bohr and Einstein in a precise way. Below the threshold, the system exists in a genuine quantum superposition: the wave function is a complete description, no objective definiteness exists, and quantum mechanics is operationally complete. This is Bohr's domain. Above the threshold, the system acquires an objective, definite classical state, independent of any observer or measuring apparatus. This is Einstein's domain.

Both positions are validated within their respective regimes and invalidated when extrapolated to the full picture. The debate was not about the nature of reality, but about its regime. The threshold is the boundary between them.

6.2. Objective Reality Without an Observer

The threshold mechanism implies that the Moon exists whether or not anyone looks at it. The collapse of the center-of-mass superposition is an objective physical event, triggered by the gravitational self-energy of the body exceeding the yield threshold of the vacuum. No

observer, no measurement apparatus, and no classical environment is required. The role of the "measurer" is played by the spacetime medium itself. The measurement problem is resolved not philosophically, but physically — the boundary is set by E_{max} , not by an act of observation.

6.3. Continuity of Spacetime

A critical feature of the model must be emphasized: the yield threshold does not imply discreteness of spacetime. Below the threshold, the vacuum behaves as a smooth elastic continuum — the standard framework of General Relativity remains fully valid. The threshold marks the limit of the elastic regime, not the breakdown of the continuum itself. What changes at the threshold is not the geometry of spacetime, but its constitutive behavior: reversible elastic deformation gives way to irreversible plastic dissipation.

This means the model does not rewrite Einstein. General Relativity is recovered exactly in the sub-threshold regime as the elastic approximation to a deeper constitutive law of the vacuum. Nor does it rewrite Hawking: the thermodynamic framework of black holes remains intact. What the threshold provides is a boundary condition — the point beyond which the elastic description must be replaced by a plastic one, and where energy dissipates rather than accumulating in a singularity.

6.4. The Arrow of Time

Below the threshold, time is an external parameter — as in the Schrödinger equation. At the bifurcation point, dissipation begins, and time becomes a physical process. The arrow of time is not fundamental, but born at the threshold: the quantum, thermodynamic, and cosmological arrows may share a common origin in the dissipation that begins when the vacuum yields.

6.5. Cosmological Constant and Dark Energy

The yield threshold E_{max} is derived from the cosmological constant Λ . Its experimental confirmation at the predicted value would establish a direct link between the large-scale structure of the Universe (Λ) and the microscopic mechanism of quantum collapse (E_{max}).

The problem of the cosmological constant — the 120-orders-of-magnitude discrepancy — is not solved, but reformulated: the question shifts from "why is the vacuum energy so small" to "how is the vacuum energy related to its yield limit." Dark energy may be understood not as a fundamental constant, but as a manifestation of the elastic regime of the vacuum — with the threshold marking the transition to a different dynamics.

7. Declaration of AI Use

The author explicitly acknowledges the collaborative use of an artificial intelligence assistant in the execution of this work. The work was conducted with Alice AI, the virtual assistant of Yandex. The AI functioned as an active technical collaborator, performing advanced formal structuring of the theoretical framework, mathematical verification of the numerical scaling grid.

8. References

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