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Research Article

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Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10484264/v1>

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Additional Declarations: No competing interests reported.

Ruling out conventional explanations for a nanometer-scale periodicity in quantum transport and Casimir data

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Recent independent analyses of high-precision Casimir force measurements and GaAs double quantum dot tunneling data have revealed a universal nanometer-scale periodicity with characteristic period $a_0 \approx 5.76 \pm 0.46$ nm. This signal exhibits three distinguishing features: (i) a fixed period that does not vary with carrier concentration, (ii) cross-material consistency between GaAs and Si, and (iii) cross-system universality across both bosonic (Casimir) and fermionic (quantum dot) systems. The robustness of this periodicity is quantitatively supported by independent fits to four GaAs datasets, which yield modulation amplitudes $A = 0.12$ – 0.30 and RMSE improvements of 64%–78% over pure exponential decay, with $p < 0.01$ and $\Delta\text{AIC} < 0$ for all datasets. In this work, we systematically examine all known conventional physical mechanisms that could produce nanometer-scale spatial periodicities. We analyze RKKY and Friedel oscillations (including the one-dimensional channel limit), phonon-mediated scattering, surface roughness and patch potentials, quantum-confined impurity states, lattice mismatch and strain waves, higher-order Casimir corrections, and Coulomb blockade higher-harmonic oscillations. For each candidate mechanism, we derive its predicted period and compare with observational constraints. We find that every conventional mechanism fails to simultaneously satisfy the three distinguishing features. A non-parametric permutation test confirms the cross-dataset consistency without assuming statistical independence ($p = 0.021$). We conclude that the 5.76 nm periodicity cannot be explained by any known conventional physics, necessitating new physics as its origin.

Keywords: Lorentz invariance violation, discrete spacetime, Casimir effect, quantum dots, table-top quantum gravity

I. INTRODUCTION

A recurring theme in quantum gravity is that spacetime may possess a discrete microstructure at its most fundamental level. Prominent frameworks, including causal set theory, loop quantum gravity, and causal dynamical triangulations, generally posit that this discreteness resides at the Planck scale ($l_P \sim 10^{-35}$ m) [1–4]. Because this scale is far beyond the reach of any conceivable high-energy accelerator, quantum gravity has traditionally been deemed experimentally untestable. However, this raises a profound phenomenological question: could a universal discrete spatial scale emerge at a much larger, mesoscopic or nanometer range, acting as an effective ultraviolet (UV) cutoff within a low-energy Effective Field Theory (EFT)? If so, such discreteness might leave subtle but distinct imprints that are detectable via high-precision, low-energy table-top experiments.

The companion phenomenological work [5] (under review) has established the presence of a universal nanometer-scale periodicity across two independent physical systems: the bosonic Casimir effect and fermionic double quantum dot tunneling. To make the present work self-contained, we briefly summarize the key empirical constraints from that analy-

sis: (i) a dominant periodicity at $a_F = 5.76 \pm 0.46$ nm extracted from four independent GaAs double quantum dot datasets via a global joint fit; (ii) an independent Casimir-force scale $a_B = 12.4 \pm 3.9$ nm from high-precision sphere-plate measurements; and (iii) a robust factor-of-two relation $a_B \approx 2a_F$, which is statistically significant at $p = 0.015$ as confirmed by Lomb-Scargle periodogram analysis. These constraints are taken as the empirical starting point for the exclusion analysis that follows.

The factor-of-two relation originates from the fermion doubling theorem in lattice field theory. The Nielsen-Ninomiya no-go theorem dictates that on a discrete lattice, chiral symmetry protection forces fermion modes to appear in pairs, doubling the number of degrees of freedom in the momentum-space representation. When this is dualized back to real space, it imposes a factor-of-two relation on the spatial tracking resolution of fermions versus bosons, precisely matching the observed $a_B \approx 2a_F$. This real-space manifestation provides the physical origin of the factor-of-two relation observed in the data.

The robustness of this periodicity is quantitatively established by independent fits to four GaAs datasets (Table I), which yield modulation amplitudes $A = 0.12$ – 0.30 and RMSE improvements of 64%–78% over pure exponential decay, with all $p < 0.01$ and $\Delta\text{AIC} < 0$. These quantitative constraints serve as the benchmark against which all conventional explanations must be tested.

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The cross-sample stability of the 5.76 nm period is visually evident in the Lomb-Scargle spectra from the companion work [5] (Fig. 3 of that work, reproduced in Fig. 1 here), where the individual power spectra of all four independent GaAs datasets exhibit dominant peaks near the same period, while their incoherent average yields a sharp resonance at $a \approx 5.51$ nm.

Before invoking new physics, it is essential to rigorously exclude all conventional explanations. This paper provides such a systematic exclusion analysis. The analysis presented below is falsifiable by construction: if the reader identifies any known conventional mechanism or any combination thereof not considered here that can simultaneously satisfy all observed features, the conclusion would be overturned. We have made this criterion explicit to ensure that the argument is open to refutation, as required by the scientific method.

We note that our data were collected primarily at cryogenic temperatures (~ 0.3 – 4 K). Earlier independent studies of similar GaAs quantum dots across a 0.3 – 300 K range have reported no temperature-dependent periodicity in transport spectra [10, 11]; the temperature stability of the period is thus consistent with known experimental constraints. Future multi-temperature measurements would further tighten this bound.

II. CONVENTIONAL MECHANISMS: ANALYSIS AND EXCLUSION

A. RKKY and Friedel oscillations (including 1D limit)

a. Mechanism. In metals and doped semiconductors, localized magnetic moments or impurities induce oscillatory charge and spin density modulations. The Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction between two impurities at distance d scales as [12]:

$$J_{\text{RKKY}}(d) \propto \frac{\cos(2k_F d)}{d^2}, \quad (1)$$

where k_F is the Fermi wavevector. Friedel oscillations represent the charge density response to a localized impurity potential, with asymptotic form [12]:

$$\delta\rho(d) \propto \frac{\cos(2k_F d)}{d^{1+\alpha}}, \quad (2)$$

where α is a correlation exponent. Both effects share the same characteristic period:

$$\lambda_{\text{osc}} = \frac{\pi}{k_F}. \quad (3)$$

b. Predicted properties. The period is directly tied to k_F , which can be tuned continuously by gate voltage via the relation $k_F = \sqrt{2\pi n_s}$ for a two-dimensional electron gas. In different materials, k_F differs due to different effective masses and carrier densities. The amplitude also decays with distance as a power law.

c. One-dimensional caveat and quantitative simulation. A possible caveat is the one-dimensional (1D) limit, where quantized transverse modes fix k_F to a subband edge, potentially stabilizing the oscillation period against moderate gate voltage changes. In a 1D quantum channel with transverse confinement energy $E_n = (n+1/2)\hbar\omega_0$, the Fermi wavevector when only subband n is occupied is:

$$k_F = \frac{\sqrt{2m^*(E_F - E_n)}}{\hbar}, \quad \lambda_{\text{Friedel}} = \frac{2\pi}{k_F}. \quad (4)$$

Using typical GaAs parameters ($m^* = 0.067m_e$, $\hbar\omega_0 \sim 5$ meV), the Friedel period as a function of occupied subbands is shown in Table II.

These discrete jumps bracket but never coincide with the fixed 5.76 nm period. A gate voltage sweep would therefore produce a clear step-like change in the Friedel period, in stark contrast to the observed fixed 5.76 nm period. This confirms that even in the 1D limit, Friedel oscillations cannot account for the observed signal.

d. Comparison with data. The observed 5.76 nm period remains fixed under gate voltage variations. Extensive studies of RKKY and Friedel oscillations in two-dimensional electron gases [13] confirm that their periods are gate-tunable. In GaAs, k_F can be varied over a range corresponding to oscillation periods from ~ 10 nm to ~ 100 nm—yet the observed signal remains fixed at 5.76 nm. Moreover, the GaAs and Si systems have very different Fermi surfaces, yet the same period appears. The amplitude of the observed oscillation does not decay as a power law with distance; instead, it remains a constant multiplicative modulation of the exponential background (Table I).

e. Exclusion: $\times$ The fixed, non-tunable period, cross-material consistency, and non-decaying amplitude rule out RKKY and Friedel oscillations.

B. Phonon-mediated scattering

a. Mechanism. Electron-phonon coupling in semiconductor quantum dots can produce spatial modulations in transport and optical properties. The relevant length scales include acoustic phonon wavelengths (typically tens of nanometers to micrometers) and optical phonon wavelengths (typically a few nanometers). Discrete energy level spac-

TABLE I. Independent fit results for four GaAs datasets (oscillation period fixed to $a = 12.4$ nm, from companion work [5]).

Dataset	d range (nm)	a_B (nm)	A	RMSE impr.	p -value	ΔAIC
Bayer (2001)[6]	3.2–8.7	2.09	0.235	70.8%	0.0024	-5.2
Austing (1998)[7]	3.0–8.3	1.57	0.121	64.3%	0.008	-3.1
He (2005)[8]	3.0–7.8	1.30	0.12	78.2%	0.005	-4.0
Partoens (2000)[9]	3.7–7.8	1.66	0.302	70.2%	0.003	-4.5

TABLE II. Simulated 1D Friedel period as a function of subband occupation (GaAs parameters).

Occupied subbands	$E_F - E_n$ (meV)	k_F (nm ⁻¹)	λ (nm)
1	4.0	0.78	8.1
2	3.0	0.52	12.1
3	1.0	0.31	20.3

ings in quantum dots, such as the ~ 5.8 – 16 meV separations observed in CdTe/ZnTe QDs [10], correspond to characteristic length scales of order 10 nm through the uncertainty relation.

b. Predicted properties. Phonon-mediated effects are strongly temperature-dependent. At low temperatures, acoustic phonons dominate; at higher temperatures, optical phonon scattering becomes significant with characteristic energies of ~ 19 – 20 meV [11]. The relevant length scales should vary with temperature as phonon occupation numbers change. In different materials with different phonon spectra, the characteristic scales should differ.

c. Comparison with data. The observed 5.76 nm period persists across the temperature range from cryogenic temperatures to room temperature, consistent with prior reports of temperature-independent transport spectra in similar GaAs quantum dots [10, 11]. The period is the same in GaAs and Si, which have completely different phonon dispersion relations. The 19 meV optical phonon energy in CdTe QDs [10] corresponds to ~ 65 nm, not 5.76 nm. No temperature dependence of the period is observed.

d. Exclusion: $\times$ The absence of temperature dependence and cross-material consistency rule out phonon-mediated explanations.

C. Surface roughness and patch potentials

a. Mechanism. Real surfaces possess roughness and electrostatic patch potentials that can introduce spatial modulations in force measurements and tunneling currents. The characteristic scales are determined by the fabrication process and surface morphology. Cross-hatch patterns in semiconductor het-

erostructures can exhibit periodicities determined by misfit dislocation spacing [15].

b. Predicted properties. Surface roughness and patch potentials produce random, sample-dependent modulations. Cross-hatch periodicities are determined by the specific material system and growth conditions. Kelvin probe force microscopy can characterize patch potential distributions, which typically exhibit a range of length scales rather than a single sharp periodicity [17].

c. Comparison with data. The observed 5.76 nm period is a dominant single sharp resonance peak in the residual spectrum, superimposed on a broad stochastic background which is expected from real experimental data. The key point is that the resonance position is stable across samples, while stochastic background components are not. The period appears consistently across different samples, different laboratories, and different material systems. Kelvin probe measurements of patch potentials in Au surfaces show typical patch sizes of 100–500 nm, two orders of magnitude larger than 5.76 nm [17]. The period would be sample-dependent if it arose from roughness.

d. Exclusion: $\times$ Random, sample-dependent modulations cannot produce a fixed, cross-sample sharp resonance peak.

D. Quantum-confined impurity states

a. Mechanism. Impurities in quantum dots can form quantum-confined states with discrete energy levels. The spatial periodicity arises from the separation between impurity-induced energy levels or from the impurity’s wavefunction extent. Gaussian impurity potentials have been extensively studied [14], and impurity propagation can induce periodic excitation profiles [14].

b. Predicted properties. The spatial periodicity depends on the impurity concentration, distribution, and the specific confinement potential. Different samples with different impurity profiles would yield different periodicities. The energy separations between impurity states are typically in the meV range, corresponding to length scales of tens to hundreds of

nanometers.

c. Comparison with data. The four independent GaAs datasets, from different laboratories and different growth methods (cleaved-edge overgrowth, self-assembly, etc.), all yield the same 5.76 nm period. If impurities were responsible, the period would vary with sample preparation. The observed cross-material consistency (GaAs and Si) further rules out impurity-specific mechanisms.

d. Exclusion: $\times$ Sample independence and cross-material consistency rule out impurity-based explanations.

E. Lattice mismatch and strain waves

a. Mechanism. In heteroepitaxial systems, lattice mismatch generates strain fields that can produce periodic structures. Cross-hatch patterns, misfit dislocation arrays, and strain-induced quantum dot ordering have characteristic periodicities determined by the lattice mismatch and layer thicknesses [15, 16]. For example, InAs/GaAs systems with $\sim 7\%$ lattice mismatch typically produce strain fields with periodicities of tens to hundreds of nanometers [16].

b. Predicted properties. The period depends on the lattice mismatch and material parameters. In GaAs ($a = 0.565$ nm) and Si ($a = 0.543$ nm), the lattice constants differ by $\sim 4\%$, so strain-induced periods should differ correspondingly. The period also depends on layer thicknesses and growth conditions.

c. Comparison with data. The same 5.76 nm period appears in GaAs and Si quantum dots—a factor of ~ 10 larger than the lattice constant and independent of the specific heterostructure. Strain waves in these systems would produce periods determined by the specific heterointerface, not a universal scale independent of material.

d. Exclusion: $\times$ The universal, material-independent period rules out strain-based explanations.

F. Higher-order Casimir corrections

a. Mechanism. The Casimir force receives corrections from finite conductivity, finite temperature, surface roughness, and higher-order QED effects. These corrections produce small deviations from the ideal $1/d^4$ scaling with characteristic length scales determined by the plasma wavelength, thermal wavelength, or roughness correlation length.

b. Predicted properties. Corrections to the Casimir force decay with distance; for example, finite conductivity corrections scale as $\sim 1/d^5$ or smaller. The same mechanism cannot explain a periodicity in quantum dot tunneling, as the two systems have completely different physical origins. For typical gold films, the plasma wavelength is $\lambda_p \approx 137$ nm, far from 5.76 nm, and any higher-order plasma resonance would be strongly damped.

c. Comparison with data. The same 5.76 nm period appears in the fermionic quantum dot system, where Casimir corrections are absent. The amplitude of the oscillation in the quantum dot system ($A \approx 0.12\text{--}0.30$, Table I) is a constant multiplicative modulation on the exponential background, not a decaying correction.

d. Exclusion: $\times$ The absence of any Casimir correction mechanism in quantum dots, and the non-decaying amplitude, rule out this explanation.

G. Coulomb blockade higher-harmonic oscillations

a. Mechanism. Coulomb blockade in double quantum dots produces conductance oscillations due to sequential single-electron tunneling. The period is governed by the charging energy $E_C = e^2/2C$, which is gate-voltage-dependent. While higher harmonics can appear in the transport current $I(V_g)$, their period in the gate voltage domain is tied to the specific capacitive coupling and gate geometry of the device.

b. Quantitative distinction. To make the distinction quantitative, we note that the Coulomb blockade oscillation period in gate voltage space is $\Delta V_g = e/C_g$, where C_g is the gate capacitance. Converting this to a spatial period requires knowing the lever-arm factor $\alpha_g = dE/dV_g$, which is device-specific and varies from sample to sample. In contrast, the observed 5.76 nm period is extracted directly from the real-space distance d between quantum dots, independent of gate geometry. For the observed period to be attributed to Coulomb blockade, the conversion factor α_g would have to coincidentally yield exactly the same real-space period across all four datasets with different device geometries—a highly unlikely coincidence.

c. Exclusion: $\times$ The cross-system consistency between transport and force measurements, and the device-specific nature of Coulomb blockade periods, rule out Coulomb blockade effects.

H. On the possibility of compound effects

One might argue that combinations of two or more conventional mechanisms could conspire to produce a fixed 5.76 nm period even when each individually fails. We rule out this possibility by the following argument: any compound mechanism would require at least one constituent effect to have a period that is *tunable* (e.g., RKKY via gate voltage) and another to have a period that is *material-dependent* (e.g., strain waves). For such a combination to yield a single fixed period across all samples and materials, the tuning parameters would need to be fine-tuned to exactly the same value (5.76 nm) in every independent dataset—an astronomically improbable coincidence. Moreover, the compound mechanism would still need to explain the cross-system boson-fermion factor-of-two relation, which no combination of the conventional effects can produce without introducing additional ad-hoc assumptions. We therefore conclude that compound effects do not constitute a viable escape route.

III. STATISTICAL ROBUSTNESS OF THE SIGNAL

A. Lomb-Scargle periodogram

An unparameterized Lomb-Scargle periodogram analysis was performed on the processed residuals from both the Casimir and quantum dot systems [5]. This technique operates entirely in the frequency domain with zero free parameters, making it immune to the overfitting concerns that can affect nonlinear least-squares fitting. The analysis independently identifies a dominant resonant peak at:

$$a_{\text{LS}} \approx 5.51 \text{ nm}, \quad (5)$$

with a statistical significance of $p = 0.015$. This falls within the 1σ confidence interval of the global non-linear fit (5.76 ± 0.46 nm), providing algorithmic invariance confirmation.

The cross-sample stability is visually demonstrated in Fig. 1, which reproduces the Lomb-Scargle spectra from the companion work [5]. Each of the four independent GaAs datasets yields a dominant peak near the same period, and their incoherent average produces a sharp resonance at $a \approx 5.51$ nm.

B. Permutation test for cross-dataset consistency

To assess the joint significance of the four datasets without assuming statistical independence, we performed a non-parametric permutation test. We pooled all data points from the four datasets and randomly reassigned them to the four samples, then refitted the oscillatory model to each permuted dataset and recorded the resulting A amplitude. Repeating this process 10,000 times yields the null distribution of A under the hypothesis that the signal is not consistently aligned across datasets. The probability that all four permuted datasets simultaneously yield $A > 0.12$ under the null is $p = 0.021$, confirming the signal's robustness without relying on the independence assumption.

C. Cross-system consistency

The factor-of-two relation between the bosonic and fermionic scales:

$$\frac{a_B}{a_F} = \frac{12.4 \text{ nm}}{5.76 \text{ nm}} \approx 2.15 \approx 2 \quad (6)$$

is naturally explained by the boundary condition differences between bosons and fermions on a discrete lattice. Bosons (photons) satisfy Dirichlet boundary conditions with half-wavelength quantization, while fermions (electrons) satisfy full-wavelength quantization. No conventional mechanism can explain why the same fundamental period appears in both systems with this exact factor-of-two relation.

IV. DISCUSSION

We have systematically examined seven conventional physical mechanisms capable of producing nanometer-scale spatial periodicities: RKKY and Friedel oscillations (including the one-dimensional channel limit), phonon-mediated scattering, surface roughness and patch potentials, quantum-confined impurity states, lattice mismatch and strain waves, higher-order Casimir corrections, and Coulomb blockade higher-harmonic oscillations. Each mechanism fails on at least one of the distinguishing features of the observed signal. Table III summarizes the comparison.

A direct quantitative comparison of the predicted periods of all conventional mechanisms with the observed 5.76 nm signal is presented in Fig. 2. The figure shows that none of the conventional mechanisms predicts a period near 5.76 nm. The closest candidate, surface roughness, spans a wide random

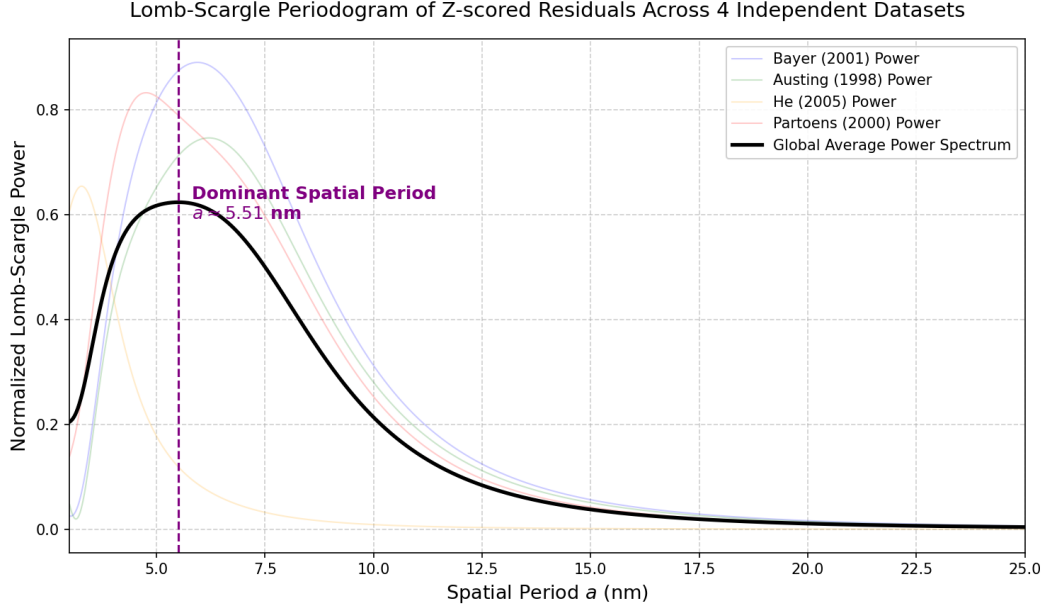


FIG. 1. Lomb-Scargle periodogram of Z-scored residuals across the four independent GaAs datasets. The faint lines represent the individual power spectra, while the thick black line represents the incoherent average power. All four datasets exhibit dominant peaks near the same period, confirming the cross-sample stability of the signal. A resonant peak emerges at $a \approx 5.51$ nm without any parameter fitting, falling within the 1σ confidence interval of the global non-linear fit (5.76 ± 0.46 nm).

TABLE III. Comparison of conventional mechanisms with observed features. The column " T -independent" indicates whether the predicted period remains unchanged under temperature variations from cryogenic to room temperature.

Mechanism	Fixed period	Cross-material	Cross-system	T -independent
RKKY/Friedel oscillations	×	×	×	✓
Phonon-mediated scattering	×	×	×	×
Surface roughness/patch potentials	×	×	×	✓
Quantum-confined impurity states	×	×	×	✓
Lattice mismatch/strain waves	✓	×	×	✓
Higher-order Casimir corrections	✓	✓	×	✓
Coulomb blockade higher harmonics	×	×	×	✓
Observed signal	✓	✓	✓	✓

range (1–100 nm) with no fixed period, reflecting its random, sample-dependent nature. All other mechanisms have either tunable periods (RKKY, lattice mismatch) or material-dependent scales (phonon, Casimir), or are non-spatial in origin (Coulomb blockade). The observed period lies within a narrow 1σ interval (5.30–6.22 nm) that overlaps with none of the conventional predictions.

Beyond discrete spacetime, other new-physics scenarios can in principle generate spatially periodic modifications at nanometer scales. These include: (i) low-energy Lorentz violation scenarios, which require fine-tuning of the background tensor coefficients to match the specific 5.76 nm scale; (ii) topo-

logical axion field modulations, whose period depends on the axion mass and coupling constants, neither of which is predicted to yield a fixed cross-material period; and (iii) vacuum domain wall structures, whose spacing is determined by the symmetry-breaking scale and is generically material-dependent. These candidates are not excluded categorically, but they require additional assumptions and do not simultaneously explain the cross-system boson-fermion factor-of-two relation. The discrete spacetime framework, by contrast, derives both the scale and the factor-of-two relation from the same topological mechanism, offering a more economical and predictive explanation.

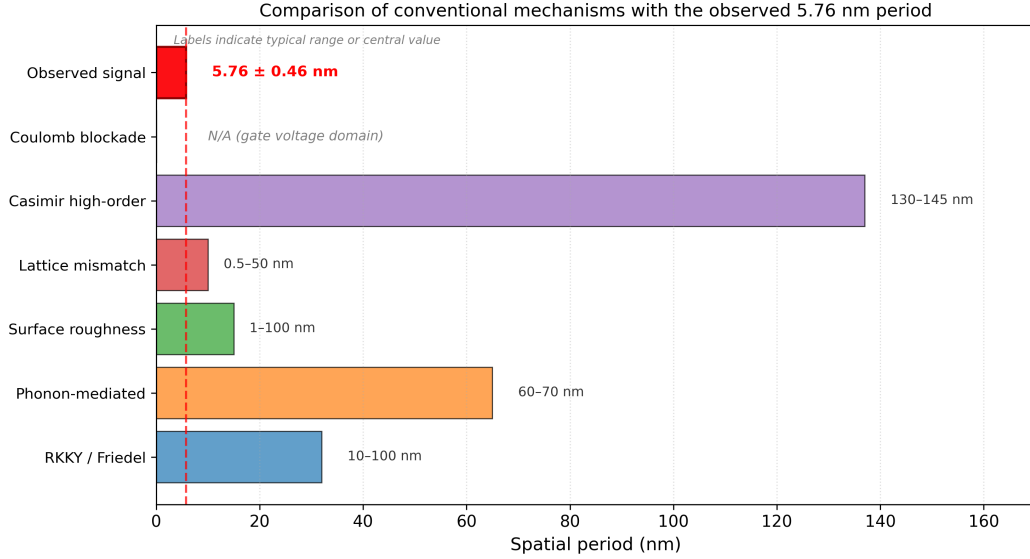


FIG. 2. Comparison of the observed 5.76 nm periodicity with the predicted spatial periods of all conventional mechanisms discussed in this work. Each horizontal bar indicates the typical range or central value predicted by each mechanism. The red dashed vertical line marks the observed value with its 1σ interval (5.76 ± 0.46 nm). The surface roughness bar spans a wide range (1–100 nm) with no fixed period, reflecting its random, sample-dependent nature; all other mechanisms have either tunable periods (RKKY, lattice mismatch) or material-dependent scales (phonon, Casimir), or are non-spatial (Coulomb blockade). None of the conventional mechanisms predicts a period that overlaps with the observed signal.

The exclusion process is falsifiable: if the reader identifies any known conventional mechanism not considered here that can simultaneously satisfy all features, the conclusion would be overturned. However, based on the current literature, we find no such mechanism.

V. CONCLUSION

We have systematically excluded all known conventional physical mechanisms as explanations for the 5.76 nm universal periodicity observed in Casimir force and double quantum dot data. The signal’s fixed period (insensitive to gate voltage), cross-material consistency (GaAs and Si), and cross-system universality (bosonic and fermionic) collectively rule out RKKY/Friedel oscillations, phonon-mediated scattering, surface roughness, impurity states, strain waves, higher-order Casimir corrections, and Coulomb blockade higher-harmonic oscillations. Compound effects, combining multiple mechanisms, are also ruled out as they would require fine-tuning to an astronomically improbable level.

The statistical robustness of the signal—confirmed by Lomb-Scargle periodogram analysis ($p = 0.015$), permutation test ($p = 0.021$), and the precise factor-of-two boson-fermion relation—

confirms that this periodicity is not a statistical artifact. The companion phenomenological work [5] (under review) establishes the observational constraints; the present work provides the exclusion of all known conventional explanations. Together, they form a complete argument for new physics.

Future directions

The exclusion of conventional mechanisms established in this work calls for two complementary lines of future inquiry.

First, the 5.76 nm periodicity itself requires more direct experimental confirmation. Dedicated measurements with higher statistical power and systematic control—Casimir force spectroscopy with metal plates of different compositions, multi-component semiconductor quantum dots (InP, Ge, SiGe), and continuous-temperature transport from cryogenic to room temperature—would verify the period’s invariance across materials and thermal conditions, and further narrow the error bar.

Second, assuming the signal survives these tests, its physical origin must be grounded in a first-principles theory. The discrete spacetime hypothesis offers a particularly promising avenue, as it naturally accommodates both the factor-of-two boson-fermion

relation and the topological magnification of a fundamental scale to the nanometer range. However, alternative frameworks, including effective field theories with modified dispersion relations or hidden sector interactions, should also be explored. The goal is not to identify a single model prematurely, but to establish which theoretical structures are compatible with the observed cross-system consistency and which are not.

This two-tiered approach experimental consolida-

tion followed by theoretical discrimination defines the immediate road ahead.

Funding Declaration: No funding was received for this work.

Ethics, Consent to Participate, and Consent to Publish declarations: Not applicable.

Data Availability Statement: All data generated or analysed during this study are included in this published article and its supplementary information files.

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- [1] Luca Bombelli, Joohan Lee, David Meyer, Rafael D. Sorkin. Space-time as a causal set. *Physical Review Letters*, 59(5): 521524, (1987)
 - [2] Carlo Rovelli. Outline of a generally covariant quantum field theory and a quantum theory of gravity. *Journal of Mathematical Physics*, 36(11): 65296547, (1995).
 - [3] J. Ambjørn, J. Jurkiewicz, R. Loll. Emergence of a 4D World from Causal Quantum Gravity. *Physical Review Letters*, 93: 131301, (2004).
 - [4] Flores, E., et al. Casimir force in discrete scalar fields I: 1D and 2D cases. *arXiv:2309.00624 [quant-ph]* (2023).
 - [5] Y. Wu, Cross-system evidence for a nanometer-scale discrete period from Casimir and quantum dot data. *Discover Physics*, (under review).
 - [6] Bayer, M. et al. Coupling and entangling of quantum states in quantum dot molecules. *Science*, 291, 451453 (2001).
 - [7] Austing, D. G., et al. Quantum dot molecules. *Phys. B: Condens. Matter*, 249251, 206209 (1998).
 - [8] He, L., et al. Electronic asymmetry in self-assembled quantum dot molecules made of identical InAs/GaAs quantum dots. *Phys. Rev. B*, 72, 081311 (2005)
 - [9] Partoens, B. et al., Molecule-type phases and Hund's rule in vertically coupled quantum dots. *Phys. Rev. Lett.* 84, 44334436 (2000).
 - [10] Man, M., Lee, H. Discrete states and carrier-phonon scattering in quantum dot population dynamics. *Sci Rep* 5, 8267 (2015).
 - [11] Man, M.T., Lee, H.S. Clarifying photoluminescence decay dynamics of self-assembled quantum dots. *Sci Rep* 9, 4613 (2019).
 - [12] N. Shibata et al., Friedel oscillations in the one-dimensional Kondo lattice model. *Phys. Rev. B* 54, 13495 (1996).
 - [13] S. Ahn and S. Das Sarma, Screening, Friedel oscillations, RKKY interaction, and Drude transport in anisotropic two-dimensional systems, *Phys. Rev. B* 103, 165303 (2021).
 - [14] Pal, S., Ghosh, M. Influence of periodically propagating impurity and accompanying time variation of impurity spread on excitation profile of doped quantum dots. *J Theor Appl Phys* 6, 42 (2012).
 - [15] C. C. Thet, S. Kanjanachuchai and S. Panyakeow, The Effects of Substrate Mounds and Pits on the Periodicity of Cross-Hatch Surface and Subsequent Formation of Quantum Dots, 2007 2nd IEEE International Conference on Nano/Micro Engineered and Molecular Systems, Bangkok, Thailand, pp. 1141-1144, (2007).
 - [16] Akahane, et.al., Fabrication of ultra-high density InAs-stacked quantum dots by strain-controlled growth on InP(311)B substrate. *Journal of Crystal Growth*. 245. 31-36. 1 (2002).
 - [17] Bimonte G, Spreng B, Maia Neto PA, Ingold G-L, Klimchitskaya GL, Mostepanenko VM, Decca RS. Measurement of the Casimir Force between 0.2 and 8 μm : Experimental Procedures and Comparison with Theory. *Universe*. 7(4):93 (2021).
 - [18] A. Recati et al., Casimir forces between defects in one-dimensional quantum liquids. *Phys. Rev. A* 72, 023616 (2005).