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Primacohedron: A Proposal Towards Solving Riemann Hypothesis

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Abstract

Unifying number theory, string amplitudes, and spacetime emergence remains a central challenge in fundamental physics. Motivated by the spectral properties of zeta functions and their proximity to Gaussian Unitary Ensemble (GUE) statistics, we propose an explicit framework—the Primacohedron—linking p-adic string resonances to an emergent geometric description of spacetime. The model unifies arithmetic quantum chaos, random matrix theory, and holography. Temporal fluctuations arise from open p-adic resonances following GUE statistics, while spatial coherence emerges through closed zeta sectors. A curvature–spectral duality defines emergent geometry, black-hole microstructure yields porous horizons, and algorithmic learning saturates the Bekenstein bound dynamically. Primacohedron thus establishes a spectral route from number-theoretic operators to spacetime dynamics, blending p-adic strings, zeta-function operators, random matrices, and holographic complexity into a single coherent synthesis. In addition, Primacohedron also suggests a concrete pathway toward a Hilbert–Polya-type operator and offers a physically motivated set of sufficient conditions under which Riemann Hypothesis (RH) would follow.

Keywords: p-adic String Theory, Dedekind Zeta Function, Riemann Hypothesis, Random Matrix Theory, Hilbert–Polya Conjecture, Emergent Geometry, Black-Hole Entropy, Holography, Complexity–Action Duality, Cosmology, Arithmetic Quantum Chaos

1. Introduction: Spectral Implications for the Riemann Hypothesis

The Primacohedron framework is deeply intertwined with the spectral structure of the Riemann zeta function. Although the present work does *not* claim a proof of the Riemann Hypothesis (RH), the machinery developed throughout the preceding sections naturally suggests a concrete pathway toward a Hilbert–Polya-type operator and offers a physically motivated set of sufficient conditions under which RH would follow. This manuscript clarifies these implications, identifies the exact mathematical gaps that remain, and outlines how the Primacohedron approach could yield a rigorous resolution [1].

2. The Hilbert–Polya Paradigm Revisited

Hilbert and Polya conjectured the existence of a self-adjoint operator H whose spectrum reproduces the non-trivial zeros of the Riemann zeta function:

$$\zeta\left(\tfrac{1}{2} + it_n\right) = 0 \quad \Longleftrightarrow \quad H\psi_n = t_n\psi_n. \tag{1}$$

Such an operator—if rigorously defined on a suitable Hilbert space—would immediately imply RH, since the spectrum of a self-adjoint operator is necessarily real.

In Sections 2–4 we introduced an adelic operator

$$H_\zeta = \bigoplus_p w_p H_p, \tag{2}$$

acting on the adelic Hilbert space $\mathcal{H} = \bigotimes_{p\leq\infty} L^2(\mathbb{Q}_p)$, with each local kernel

$$K_p(x,y) = |x-y|_p^{-1-it_p}, \tag{3}$$

encoding a prime-indexed resonance. The global object H_ζ is constructed precisely to mimic the structure demanded by the Hilbert–Polya framework.

If H_ζ can be shown to be:
1. densely defined,
2. essentially self-adjoint,
3. possessing a discrete spectrum equivalent to $\{t_n\}$,
then RH follows immediately. The Primacohedron formalism supplies a physically motivated candidate for H_ζ; what remains is analytical rigor.

3. Conditions Under Which the Primacohedron Implies RH

Sections 3 and 4 relate the zeta zeros to the spectral density of H_ζ via the explicit formula

$$\rho_{\text{osc}}(t) = -\frac{1}{\pi}\sum_p \sum_{m=1}^{\infty} \frac{\ln p}{p^{m/2}} \cos(t\, m \ln p), \tag{4}$$

originating from prime periodicities. This structure demonstrates:
• the arithmetic spectrum uniquely determines prime data, and
• prime data uniquely determines $\rho(t)$ of the operator H_ζ.

Thus, if the following two statements can be made *rigorous*:
(A) The operator H_ζ is self-adjoint.
(B) Its oscillatory spectral component coincides exactly with $\rho_{osc}(t)$.
then

$$\text{spec}(H_\zeta) = \{t_n\} \quad \Longrightarrow \quad \text{Re}\, s_n = \tfrac{1}{2}. \tag{5}$$

The Primacohedron therefore provides an *adelic spectral route* to RH.

4. Emergent Geometry As A Consistency Constraint

Within the Primacohedron, spacetime geometry emerges from spectral rigidity, arithmetic coherence, and GUE universality. These properties are deeply connected to RH:

1. **GUE statistics of the zeta zeros** arise naturally from the arithmetic randommatrix ensembles of Section 3.3. If the ensemble is shown to be *exactly* isospectral to H_ζ, RH would follow.
2. **Spectral rigidity** is equivalent to the strong form of Montgomery–Odlyzko universality. The Primacohedron produces this rigidity as a curvature-flattening effect.
3. **Closed-string (Dedekind) coherence** suppresses off-critical-line instabilities.
4. Deviations from $\text{Re}(s) = 1/2$ correspond to geometric curvature singularities. The adelic consistency relation prohibits such singularities.

Thus, in the emergent-geometry interpretation, RH is equivalent to the absence of curvature anomalies in the spectral manifold.

5. A Roadmap to A Possible Proof

To turn the Primacohedron into an actual proof, three mathematical steps would need to be completed:

(1) Rigorous operator construction. Define the adelic operator H_ζ on a wellspecified Hilbert space. This requires establishing the domain, symmetry, closability, and self-adjointness of the p-adic kernels and their adelic sum.
(2) Exact spectral correspondence. Prove that the oscillatory part of the spectral density of H_ζ is *exactly* the explicit zeta formula. Physically this is clear; mathematically it requires analytic continuation, control of ultrametric integrals, and precise trace-class bounds.
(3) Uniqueness of spectral reconstruction. Show that no other spectrum yields the same prime-generated oscillatory pattern. This is equivalent to a one-to-one inversion of the explicit formula, believed to be true but not yet proven.

If completed, these steps would formalize the Primacohedron as a bona fide Hilbert–Polya operator, giving a proof of RH.

6. Summary

The Primacohedron does *not* prove RH. But it contributes three powerful structural insights:

1. A concrete physical candidate for the Hilbert–Polya operator arising from p-adic resonances and adelic amplitudes.
2. A geometric interpretation of the critical line, where $\mathrm{Re}(s) = 1/2$ corresponds to flat spectral curvature.
3. A unification of RMT universality, explicit formulas, p-adic string amplitudes, and holographic geometry, showing RH as a compatibility condition of the entire adelic structure.

In this way, RH becomes not merely a number-theoretic conjecture but a *global consistency law of arithmetic spacetime*. The framework suggests that if emergent spacetime is indeed adelic and spectral, as proposed here, then the Riemann Hypothesis is not only natural but perhaps *necessary*.

References

1. Setiawan, S. (2025). Primacohedron: A p-Adic String and Random-Matrix Framework for Emergent Spacetime. *Adv Theo Comp Phy, 8*(4), 01-61.