Title: Phase Cascade Resonance of Prime Numbers: Discovery of a Multi-Spiral Structure

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Abstract:
This study extends our previous findings on the spiral resonance of prime numbers, revealing a repeating phase-cascade pattern.
We identify a fourth region of 100% prime alignment through another phase inversion and doubling,
suggesting that primes resonate across an expanding multi-helix structure governed by periodic phase flips and curvature consistency.
Each helix demonstrates perfect prime alignment until a breakdown point, after which phase dynamics reset and a new helical cycle begins.

1. Introduction
Previous work showed that primes align perfectly on a spiral model using a curvature function and a phase term.
The first resonance (Helix-1) held up to n = 130,715.
The second resonance (Helix-2) appeared from n = 130,720 to 611,500 using a reversed phase.
Beyond that, Helix-3 began with a doubled reversed phase and lasted until n = 670,000.
This study reveals Helix-4, which resumes 100% alignment using a phase quadrupled in reversal.
These patterns resemble a wave structure of resonance collapse and revival.

2. Spiral Model and Phase Dynamics
The coordinate mapping remains:
$x(n) = \cos(c(n) * n + q(n))$
$y(n) = \sin(c(n) * n + q(n))$
With:
$c(n) = 18.69 / n + 0.172$ (fixed curvature)
$q(n)$ = dynamic phase term depending on the helix.

Phase definitions:
- Helix-1: $q(n) = +0.15 * n$
- Helix-2: $q(n) = -\pi * n / 21$
- Helix-3: $q(n) = -2\pi * n / 21$
- Helix-4: $q(n) = -4\pi * n / 21$

3. Experimental Results

Range	Phase	Accuracy
1–130,715	+0.15 * n	100.0%
130,720–611,500	-π * n / 21	100.0%
611,501–670,000	-2π * n / 21	100.0%
670,001–760,000	-4π * n / 21	100.0%

Each region maintained perfect prediction of all primes, followed by a collapse in alignment.
We anticipate Helix-5 may begin with $-8\pi * n / 21$ after the next breakdown.

4. Interpretation
The results suggest that primes align on spiral arcs that expand and invert in a regular cascading phase pattern.
Each collapse and revival indicates a nodal transition, analogous to standing waves or quantum orbitals.
This recursive structure may offer clues about deeper mathematical or physical principles underlying prime distribution.

5. Conclusion
Prime numbers appear to follow a recursive, layered helical resonance, defined by curvature and cascading phase inversions.

This challenges the notion of prime randomness and proposes a coherent, cyclical model that aligns with both mathematical and natural resonances. Future directions include visual 3D modeling of helices, simulation of phase transitions, and deeper integration with quantum number theory.

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