

Research Statement

CPT-Symmetric Universe: A Unified Theory for Cosmology & Fundamental Physics

Summary for the Informed Layperson

How did the universe begin? This question is not just for curiosity, but also is vital for unifying the physics of very large (cosmology) and very small (particles) –at the Big Bang. The standard model can successfully explain most phenomena, but still problems remain. My research investigates a simple and unified solution: the **CPT-Symmetric Universe**.

This model suggests that the Big Bang was not a beginning from nothing, but a mirror reflection. It postulates that our universe was created alongside a "mirror universe" (anti-universe) where time runs backward relative to us. This single assumption of symmetry naturally explains why the universe is smooth, the nature of dark matter and dark energy, etc, without needing the complex additions to the standard theory.

My work focuses on developing this theory. During my PhD, I theoretically predict the shape of such a universe and compared these predictions with data from space telescopes. I also derived the physical origin of this symmetry, elevating it from a hypothesis to a physical requirement. In my future research, I aim to extend this framework to explain other important problems in cosmology and fundamental physics.

Introduction: A Minimalist Paradigm

My research is driven by a foundational question: *Can the complexity of the observed universe and fundamental physics emerge from a minimal, unified principle?* This pursuit has led me to investigate the **CPT-Symmetric Universe**. Proposed by Boyle and Turok, this model postulates that the universe did not emerge from nothing, but was created as a universe/anti-universe pair, with the Big Bang acting as a CPT (Charge, Parity, Time) mirror between them¹. Surprisingly, this simple assumption can solve lots of phenomena uniformly, such as the nature of dark matter and cosmic homogeneity². My doctoral research has focused on two projects within the CPT-symmetric framework.

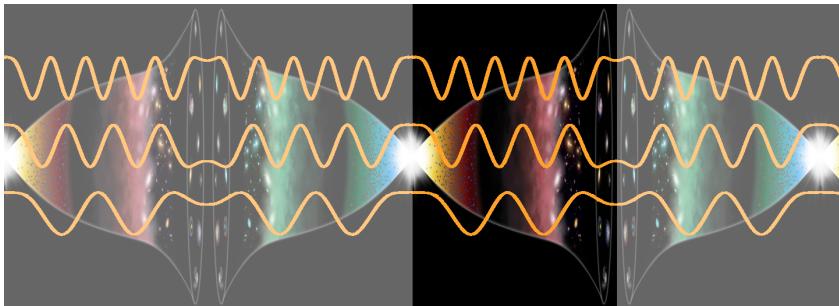


Figure 1: The CPT-Symmetric universe and periodic cosmic perturbations (orange curves).

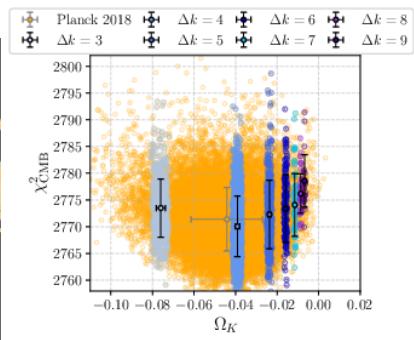


Figure 2: Observationally preferred values (lowest $\Delta\chi^2$) of cosmic curvature Ω_K .

Doctoral Research: From Phenomenology to Foundational Theory

1. Theoretical Prediction for Cosmic Curvature

Cosmic curvature dictates the evolution and ultimate fate of our universe, which often treated as a free parameter³. Instead, we showed that it is a predictable quantized value. Just as a musical instrument supports discrete frequencies, the periodic structure of the CPT-symmetric universe supports quantized modes⁴ (see fig. 1). If the universe is closed, the finite spacetime further restricts these modes to integers, implying spatial curvature to specific quantized values.

¹ L. Boyle et al., 2018, DOI: 10.1103/PhysRevLett.121.251301 ² L. Boyle et al., 2021, DOI: 10.48550/arXiv.2110.06258; L. Boyle et al., 2022, DOI: 10.48550/arXiv.2208.10396; L. Boyle et al., 2024, DOI: 10.1016/j.physletb.2024.138442; N. Turok et al., 2023, DOI: 10.48550/arXiv.2302.00344 ³ Planck Collaboration, 2020, DOI: 10.1051/0004-6361/201833910 ⁴ A. N. Lasenby et al., 2022, DOI: 10.1103/PhysRevD.105.083514

In our papers⁵, we presented the first theoretical predictions and compared them against observed data⁶. We found that the observed curvature aligns well with our predictions, providing an intriguing explanation for the nature of cosmic curvature.

2. The Quantum Basis of CPT Symmetry: Kähler-Dirac (KD) Fermions

Could we provide a physical explanation of the symmetry? We investigated this question using the KD equation⁷, a generalization of the Dirac equation that is well-defined in curved spacetime.

We quantized the KD field and found that half the modes possessed unphysical negative energies. We resolved this problem by quantizing fields across the pair universes: positive/negative energy in universe/anti-universe. Moreover, they should be CPT-symmetric to avoid causality violations, showing that this symmetry is not a random assumption, but physically required⁸!

This finding has profound physical implications. It does not just simplifies the expression of the Standard Model, but also provides solution for numerical simulating particles. Details will be explained in the proposed research.

Proposed Research for the Junior Research Fellowship

My proposed research contains three interconnected projects.

1. A New Foundation for Fermions: The Kähler-Dirac Field on the Lattice

The KD field is not solely applicable to cosmology; it is famous for its potential to solve the "fermion doubling problem"⁹, which prevents consistent lattice simulations of chiral gauge theories¹⁰, such as the electroweak sector. However, anomalies remain. We propose that considering KD fields on two spacetime sheets provides an "anomaly cancellation" mechanism. I aim to construct an explicit lattice formulation to enable first-principles simulations of chiral gauge theories. Success in this endeavor would represent a major breakthrough in particle physics, finally allowing the exploration of complicated phenomena via numerical simulation.

2. The Origin of Mass: A Composite Higgs from Dimension-Zero Scalars

It is widely accepted that dark energy arises from the quantum vacuum energy of particles; however, there is a vast discrepancy between theoretical predictions and observed values. The CPT model resolves this by adding 36 "dimension-zero" scalar fields¹¹. Moreover, these scalars can generate scale-invariant perturbations (the seeds of galaxies), a phenomenon traditionally attributed to cosmic inflation. However, this implies the Higgs boson is composite, analogous to the proton being composed of quarks. One hypothesis is that the Higgs boson is formed by these "dimension-zero" scalar fields. I will tackle the challenge of constructing a viable theory to unify origin of mass and cosmic structure.

3. Quantum Gravity as the Architect of the Cosmos

I will also investigate an alternative hypothesis regarding cosmic structure: is it a purely gravitational phenomenon? I will explore this possibility using Quadratic Gravity, a renormalizable quantum gravity theory often discarded due to "ghosts," which may actually be benign¹². Intriguingly, initial work suggests that the dynamics of quadratic gravity in the early universe can also generate a scale-invariant spectrum, mimicking the effect of dimension-zero scalars. This raises a decisive question: were the seeds of cosmic structure planted by a new form of matter, or by the quantum nature of space-time itself? Answering this requires not only tackling deep theoretical problems but also comparing predictions with observational data.

In summary, the CPT-Symmetric Universe represents a compelling, unified paradigm. I intend to extend this model for solving more problems in fundamental physics. Beyond theory, I will leverage my experience in Bayesian inference, AI, and ML to confront it with observation data. Transform this elegant hypothesis into a rigorous, testable theory.

⁵ W.-N. Deng et al., 2025; W.-N. Deng et al., 2024, DOI: 10.1103/PhysRevD.110.103528 ⁶ W.-N. Deng et al., 2025 ⁷ E. Kähler, 1962, DOI: 10.1007/BF02992927 ⁸ L. Boyle et al., 2025 ⁹ I. Montvay et al., 1994 ¹⁰ H. Nielsen et al., 1981, DOI: [https://doi.org/10.1016/0370-2693\(81\)91026-1](https://doi.org/10.1016/0370-2693(81)91026-1) ¹¹ L. Boyle et al., 2021, DOI: 10.48550/arXiv.2110.06258 ¹² J. F. Donoghue et al., 2021