Ailun (Alan) Zhang

Graduate Student in Theoretical Physics · Perimeter Institute for Theoretical Physics & McMaster University

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Research Interests

Theoretical cosmology, effective field theory, quantum gravity, the cosmological constant and dark energy, the early universe and vacuum stability, mathematical relativity, ultralight dark matter, and black-hole dynamics.

Education

Perimeter Institute for Theoretical Physics & McMaster University Sep 2026 – present

M.Sc. in Physics (thesis), McMaster University; Associate Graduate Student, Perimeter Institute

- Supervisor: Clifford P. Burgess; expected completion 2028

Australian National University Jul 2022 – Jun 2026

Bachelor of Philosophy (Honours) in Science, Specialisation in Physics, with First Class Honours

- **Final Honours Grade 92/100** (H1, honours-year average); thesis 94/100 (University Medal level); GPA 7.0/7.0
- Thesis: *Orbital Dynamics of Black Holes in Ultralight Dark Matter Solitons: Eigenmode Excitation and Stone Skipping*
- Supervisors: Brian P. Schmidt and Richard Easther

University of Auckland Jul 2024 – Feb 2025

Exchange student; research in theoretical cosmology with Richard Easther; GPA 9.0/9.0

Honours and Awards

Terrell International Undergraduate Scholarship, ANU; 50% tuition waiver (about AUD 100,000) 2023

Stephen FitzGerald Scholars Program, Australian National University 2023

Chancellor's Letter of Commendation, ANU; for outstanding academic performance 2022 – 2025

Publications and Preprints

Journal articles and preprints

[5] **A. Zhang**, "Gauge Field Fluctuations Protect the Higgs Vacuum When a Small Universe Begins," arXiv:2610.28704 [hep-ph] (2026).
To be submitted to Phys. Rev. Lett. as the companion letter to [4].

[4] **A. Zhang**, "A Casimir turning point as the beginning of a small flat universe," arXiv:2610.24905 [gr-qc] (2026).
To be submitted to Phys. Rev. D.

[3] Y. Zhou and **A. Zhang**, "Null Completeness and Directional Rigidity in Bianchi I Spacetimes," arXiv:2608.29556 [gr-qc] (2026).
Under review at Eur. Phys. J. C.

[2] J. Tang, K. Grasha, T. Różański, M. R. Krumholz, and **A. Zhang**, "The Cluster Completeness Correction Calculator (c-4): A neural-network framework and pilot application to the LEGUS survey of NGC 628," *Mon. Not. R. Astron. Soc.* **550**, stag1219 (2026), doi:10.1093/mnras/stag1219, arXiv:2604.05291 [astro-ph.IM].

[1] **A. Zhang**, Y. Wang, J. Luna Zagorac, and R. Easther, "Stone Skipping Black Holes in Ultralight Dark Matter Solitons," arXiv:2602.11512 [astro-ph.CO] (2026).
Under review at Phys. Rev. D; revised in response to referee reports.

Thesis

[T] **A. Zhang**, *Orbital Dynamics of Black Holes in Ultralight Dark Matter Solitons: Eigenmode Excitation and Stone Skipping*, B.Phil. (Hons) thesis, Australian National University (2026), doi:10.25911/3Y70-J554.

Technical reports

[R1] **A. Zhang**, "Developing a 3D Eigenfunction Decomposition of Schrödinger–Poisson Solitons" (2025), doi:10.13140/RG.2.2.23953.75363.

[R2] **A. Zhang**, "Enhancing Cosmic Ray Propagation Models: Integrating Spallation Mechanisms into the `criptic` Software for Accurate B/C Ratio Analysis" (2024), doi:10.13140/RG.2.2.21652.10883.

[R3] **A. Zhang**, "Upgrading Nebular Emission in Stellar Population Synthesis to the JWST Era" (2024), doi:10.13140/RG.2.2.31718.43847.

Research Experience

Graduate Research, Perimeter Institute & McMaster University Sep 2026 – present
Quantum cosmology and vacuum stability · Independent research

- Showed that the negative Casimir energy of Standard Model fields can turn a contracting flat three-torus universe around, as a beginning rather than a bounce, with a test in the cosmic microwave background [4].
- Showed that zero-point fluctuations of gauge-field zero modes protect the metastable Higgs vacuum as such a universe begins, giving a test through the top-quark mass at FCC-ee [5].
- With Ye Zhou: proved that a single null geodesic complete in both directions forces a Bianchi I spacetime to be static under one-sided null-curvature conditions [3].

Honours Thesis Research, Australian National University & University of Auckland Jul 2024 – Jul 2026
Ultralight dark matter and black-hole dynamics · Supervisors: Brian P. Schmidt and Richard Easther

- Identified a dipole excitation of the soliton as the driver of quasi-periodic "stone-skipping" black-hole orbits [1, T].
- Built a 3D Schrödinger–Poisson eigenmode decomposition on `PyUltraLight` to reconstruct excited solitons [R1].
- Reduced the coupled dynamics to a forced, damped oscillator, clarifying the resonance and its consequences for inspiral timescales, the final-parsec problem, and gravitational-wave observations.

Undergraduate Researcher, Swinburne University of Technology Jun 2025 – Aug 2025
Primordial black holes and cosmology · Supervisor: Edward Taylor

- Built a Python framework for Hawking emission of massless species from Schwarzschild primordial black holes, working with the group's study of a new candidate.
- Studied primordial black holes as a matter-to-radiation conversion channel after recombination, and quantified how accretion of the cosmic microwave background suppresses their cosmological impact in the allowed mass range.

Undergraduate Research Assistant, Australian National University Feb 2024 – Jun 2024
Cosmic-ray propagation · Supervisors: Mark R. Krumholz and Roland Crocker

- Reviewed spallation in cosmic-ray transport and the B/C ratio as a constraint on interstellar propagation; proposed extensions of the `criptic` code to include spallation of heavier nuclei [R2].

Undergraduate Research Assistant, Australian National University Jul 2023 – Feb 2024
Stellar population synthesis · Supervisor: Mark R. Krumholz

- Implemented a table-based nebular-emission model in the `SLUG` code for young star clusters in the JWST era [R3]; the upgrade generated the synthetic-cluster library of the c-4 framework (Appendix B of [2]).

Teaching Experience

Teaching Assistant, Department of Physics & Astronomy, McMaster University Sep 2026 – present
PHYSICS 1D03: Introductory Mechanics (tutorials of about 40 first-year engineering students)

- Lead tutorials, teaching and guiding students through a series of Python-based Jupyter notebooks and exercises tied to the course laboratories.
- Assist the instructor in interactive lectures, guiding student discussion and answering questions.

PHYSICS 2C03: Modern Physics (special relativity and introductory quantum physics; over 100 students)

- Facilitate in-class quizzes and peer discussion; mark quizzes and assignments.

Academic Service

Abstract Reviewer, 61st Canadian Undergraduate Physics Conference (CUPC 2026) Sep 2026
Hosted by McMaster University, Hamilton, ON, 15–18 October 2026

- Blind-reviewed seven research abstracts on five criteria and wrote feedback for the authors.

Conferences and Schools

Strings 2026, 36th Annual Strings Conference, Shanghai, China Jul 2026

Pre-Strings School 2026, Shanghai Institute for Mathematics and Interdisciplinary Sciences Jun – Jul 2026

Computational Skills

Programming: Python (scientific computing, Jupyter), C++, Mathematica. **Methods:** Schrödinger–Poisson simulation, eigenmode and spectral analysis, scientific data analysis. **Tools:** LaTeX, Git, GitHub.