

Kangqiao Liu

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Machine Learning Researcher & Theoretical Physicist

Research Profile

I study stochastic learning dynamics and theoretical models of complex systems. My earlier machine-learning work developed finite-learning-rate theories of SGD noise, minibatch fluctuations, and escape dynamics; my recent work has focused on nonequilibrium response, quantum information, and mathematically controlled dynamical problems. I am now bringing these lines back together around reasoning dynamics, scientific AI, and verifiable autonomous discovery.

Research Focus

- **Stochastic optimization and training dynamics:** finite-learning-rate SGD, minibatch noise, escape and rare-event dynamics.
- **Reasoning and scientific AI:** dynamics of search and reasoning, verifiable scientific agents, research-grade evaluation environments.
- **Theoretical modeling:** stochastic processes, nonequilibrium response, information-theoretic bounds, quantum and complex dynamics.

Selected Machine Learning Research

Noise and Fluctuation of Finite Learning Rate Stochastic Gradient Descent

ICML 2021

K. Liu*, Z. Liu*, M. Ueda – equal contribution

Developed a discrete-time theory of SGD at finite learning rate, deriving analytical noise and parameter-fluctuation formulas and stability boundaries beyond continuous-time Langevin approximations.

paper arXiv

Strength of Minibatch Noise in SGD

ICLR 2022 Spotlight

Z. Liu*, K. Liu*, T. Mori, M. Ueda – equal contribution

Analyzed minibatch noise in discrete-time SGD and derived how noise strength and model fluctuations depend on learning rate, batch size, width, and regularization.

paper arXiv

Power-law Escape Rate of SGD

ICML 2022 Spotlight

T. Mori, Z. Liu, K. Liu, M. Ueda

Derived the stationary distribution around local minima and identified power-law escape dynamics for minibatch SGD, linking optimization escape to the loss-dependent structure of stochastic noise.

paper arXiv

Selected Independent Research

Dynamical activity universally bounds precision of response in Markovian nonequilibrium systems

Commun.

Phys. 2025

K. Liu, J. Gu – Established a universal kinetic bound connecting static response precision to dynamical activity in nonequilibrium Markov processes.

journal arXiv

Classical codes violate the conjectured square-root bound for quantum random access codes

2026 preprint

K. Liu (sole author) – Constructed a family of counterexamples and characterized the asymptotic region between the conjectured square-root curve and Nayak's entropy bound.

arXiv

Maximal-velocity deficit under a finite-support constraint in a hard-wall half-line continuous-time quantum walk

PRA 2026

K. Liu, D. Chen – Reduced an optimal transport problem to a principal-eigenvalue problem and derived the exact asymptotic velocity deficit under finite-support preparation.

journal arXiv

Current Direction and Research Tooling

- Developing a research program that connects stochastic-process methods with modern reasoning and agent systems: trajectory ensembles, search dynamics, verification, failure recovery, and compute allocation.
- Exploring verifiable scientific-agent environments built from genuine mathematical and physical research tasks, with emphasis on mechanisms and evaluation signals that remain meaningful beyond a single model generation.
- Built **Scientific Manuscript Audit**, an open-source research workflow for Codex and Claude Code with claim-to-evidence tracing, synthetic evaluation cases, automated validation, and reproducible distribution packages. GitHub

Experience

- 2023–present** **Lecturer of Physics**, School of Science, Xihua University, Chengdu, China. Independent research in nonequilibrium physics, quantum information, stochastic dynamics, and machine learning.
- 2020–2023** **Ph.D. in Physics**, The University of Tokyo, Japan. Advisor: Prof. Masahito Ueda. Thesis: *Theoretical Study on Information Engines for Quantum Transport*.
- 2018–2020** **M.Sc. in Physics**, The University of Tokyo, Japan. Advisor: Prof. Masahito Ueda. Thesis: *Thermodynamic Uncertainty Relations in Markovian Processes*.

Selected Funding

- **National Natural Science Foundation of China, Young Scientists Fund (Category C)**, Principal Investigator, CNY 300,000, 2027–2029. Project on current precision and response bounds in coherent quantum transport and open quantum systems.
- **Xihua University Scientific Research Start-up Foundation**, Principal Investigator, 2024–2026.
- **JSPS DC2 Grant-in-Aid for Research Fellow**, Principal Investigator, 2023.

Selected Publications Beyond ML

- K. Liu, Z. Gong, M. Ueda, *Thermodynamic Uncertainty Relation for Arbitrary Initial States*, **Physical Review Letters** **125**, 140602 (2020).
- K. Liu, J. Gu, *Response kinetic uncertainty relation for Markovian open quantum systems*, **Physical Review A** **113**, 062443 (2026).
- K. Liu, M. Nakagawa, M. Ueda, *Maxwell’s demon for quantum transport*, **Physical Review A** **113**, 022436 (2026).
- J. Gu, K. Liu, *Finite-frequency fluctuation-response bounds for open quantum systems*, accepted in **Quantum Science and Technology** (2026).

Technical and Research Skills

- **Programming / research computing:** Python, PyTorch, NumPy/SciPy, Jupyter, Git, Linux, reproducible numerical workflows.
- **Research methods:** stochastic-process modeling, optimization theory, analytical derivations, numerical experiments, benchmarking and evaluation design.
- **Scientific communication:** LaTeX, reproducible research packages, technical writing and peer review across machine learning and physics.

Academic Service

Reviewer for **NeurIPS**, **ICLR**, **ICML**; **Physical Review Letters**, **Physical Review Research**, **Physical Review E**, **Communications Physics**.

Selected Recognition

- ICLR 2022 Spotlight; ICML 2022 Spotlight.
- National Scholarship, Ministry of Education of China (2015); Wuhan University Honors graduate (2018).