Summer School 2026: *Quantum algorithms for physics: quantum simulations and open systems.*

Summary: Basics of open quantum systems, with a particular focus on the many-body regime and on the process of reaching thermal equilibrium, covering key notions such as mixing times and quantum detailed balance. Quantum simulation and many-body theory basics required for efficient quantum algorithmic simulation of thermalization and open systems.

References for parts of the course

- Daniel Lidar's notes on open systems: https://arxiv.org/abs/1902.00967
- Lieb-Robinson bound for open systems & simulation: https://arxiv.org/abs/1003.3675 https://arxiv.org/abs/1111.4210
- Collision model derivation: Appendix B https://arxiv.org/abs/2506.21318
- Mixing times of quantum chanels: https://arxiv.org/abs/1005.2358 https://arxiv.org/abs/1207.3261
- Quantum algorithms & singular value transform: Sec 4 https://www.cs.umd.edu/~amchilds/qa/ and https://arxiv.org/abs/2105.02859

Background & Prerequisites

- **Quantum Mechanics Foundation:** Hamiltonian dynamics, Schrödinger equation, quantum channels, quantum states, purifications, Stinespring dilation
- **Mathematics of quantum information:** trace distance, relative entropy, quantum computation basics & circuits (no algorithms necessary)

Lecture Schedule

Lx: lecture x, Tx: tutorial x

L1: Open system basics

- Quantum channels and CPTP maps, Kraus representation
- Mathematical derivation of Lindbladian as a differential CPTP map to first order
- Physical derivation of a Lindbladian in the collision model paradigm
- (Time-permitting) Master equations beyond Lindbladians: Redfield and TCL

T1: Open system tutorial

- Examples of generators (primitive and not)
- Fixed points & conditions for uniqueness
- Gap & speed of convergence (fast vs. rapid mixing)

L2: Many-body theory

- Proof of the Lieb-Robinson bound and generalization to open systems
- Applications to classical & quantum simulation

L3: Mixing & Thermalization

- Classical Markov chains & detailed balance
- Quantum detailed balance & the rotating wave approximation

- GNS vs. KMS detailed balance
- Lamb shift and quasi-locality of KMS detailed balance

T2: Many-body tutorial
- Equivalence of variants of the Lieb-Robinson bound (commutator vs. partial trace)
- Clustering of correlations from rapid mixing
- TBD

L4: Quantum algorithms for quantum simulation
- Trotterization (closed vs. open systems)
- Quantum signal processing basics (QSP)
- Open systems via QSP
- Quantum algorithms for thermalization