# Complex quantum systems: learning and simulation

Many-body quantum systems are ubiquitous in theoretical and experimental quantum information processing, from the simulation of condensed matter systems to the development of good quantum error-correcting codes. Recent years have seen major developments in our mathematical understanding of these systems' intricacies. In these lectures, we will explore the complexity of physically motivated models of many-body quantum systems, from ground and thermal states of matter to outputs of short-time quantum evolutions. We will consider two notions of complexity: (i) the computational hardness of simulating properties of the system (a.k.a. forward problem); and (ii) the learnability of classical descriptions of the system from access to samples (a.k.a inverse problem).

Prerequisites

- Basics of quantum statistical inference
- Basics of quantum computing
- Linear algebra

The course will consist in 26 hours of lectures punctuated with 6 hours of exercises

## Part 1: Sampling

- Lecture 1: Simulating real time dynamics, Trotterization, Lieb-Robinson bounds [2h]

- Lectures 2-3: The local Hamiltonian problem, QMA hardness of computing the ground state energy, connections to classical optimization [4h]

- Lecture 4: Adiabatic and variational quantum algorithms [2h]

- Lectures 5-6: Quantum Gibbs sampling and partition function estimation [4h]

## Part 2: Learning

- Lectures 1-2: Learning quantum systems in trace distance: single copy algorithms, Schur-Weyl duality, optimal algorithms [4h]

- Lectures 3-4: Learning expectation values of a set of quantum observables: shadow tomography, classical shadows [4h]

- Lecture 5: Learning the Hamiltonian of a many-body systems from Gibbs states [2h]

- Lectures 6-7: Learning the Hamiltonian of a many-body system from time evolution [2h], Learning tensor networks in 1D [2h]