Physics 578, Spring 2022

Quantum Information and Simulation for Scientific Applications

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With the recognition of the future potential for simulating structure and dynamics of physically relevant quantum systems that cannot be addressed with classical computing, and the rapid advances in the capabilities of a growing array of quantum devices, first quantum simulations of small model quantum field theories and many-body systems using available NISQ-era quantum devices have started to be performed. The beginning of the Quantum-2 era that this progress heralds has been brought about by remarkable advances across the sciences and engineering, from materials to algorithms, toward precision control of coherence and entanglement in the laboratory for sensing and computing, and their integration. This special topics course in theoretical physics brings together the vision and research at the forefront of quantum information science, quantum computing and theoretical physics that is enabling the early progress in quantum simulations of quantum systems of future importance for scientific applications, including for nuclear physics, particle physics, and also quantum computers and simulators.

Prerequisites: Phys 517/8/9

Tentative Syllabus:

Week-1: The background, vision and complexity of classical and quantum simulation of quantum systems, including long-term scientific goals, universal quantum computing and bounded error computation.
Week-2: Entanglement - relevant aspects
Week-3: Gaussian Systems of continuous variables– relevant aspects. Covariance matrices, correlators, entanglement entropy, negativity, separability.
Week-4: Entanglement in quantum fields
Week-5: Lattice Hamiltonian Scalar Field Theories – construction and quantum circuits
Week-6: Quantum simulation of quantum field theories: state preparation and time evolution
Week-7: Quantum simulation of quantum field theories: observables and measurements
Week-8: Quantum simulation of Lattice Gauge Theories
Week-9: Error mitigation strategies in quantum simulations using NISQ-era devices
Week-10: Error correction frameworks
Week-11: AdS/CFT and Entanglement: Ryu-Takanagi, error correction, Ising theory