The Road to Quantum Computing: Quantum Transport across Superconducting Junctions

Quantum computing promises a revolutionary shift in our ability to process information, leveraging the principles of quantum mechanics to outperform classical systems. In this colloquium, we explore the theoretical and physical underpinning ideas of topological quantum computing (TQC), with a focus on the role of quantum transport in superconducting junctions.

We begin with a conceptual overview of quantum computation, highlighting the fundamental dilemma in quantum computing: the trade-off between coherence and operation speed. TQC offers a resolution to this challenge by enabling non-local storage and manipulation of information through **Majorana zero modes (MZMs)** — preserving both coherence and speed.

The talk delves into key ideas of TQC, including topological superconductors, MZMs, non-Abelian braiding statistics, and quantum transport in engineered nanostructures. Recent theoretical developments and experimental architectures, including proposals from Microsoft and our own research, will be discussed.

This journey — from fundamental principles to practical implementations — outlines the road toward realizing a topological quantum computer, where quantum information can be stored, manipulated, and measured without ever “opening the box.”