

---

## *Numerical simulation of strongly correlated quantum many-body systems*

---

Contact: Valentin Crépel, [valentin.crepel@utoronto.ca](mailto:valentin.crepel@utoronto.ca)

### **Research description:**

My research group explores some of the most fascinating frontiers in condensed matter physics: Topological phases of matter that look identical locally but differ by global invariants encoded in the topology of their wavefunctions; High-temperature superconductors, which promise dissipationless energy transport by forming atomic-scale electron pairs through forces so strong they overcome the diverging Coulomb repulsion at small distance; Fragile correlated electron states, hosting excitations that carry only a fraction of the electronic charge, and thereby defy the standard model of particle physics. To study and advance our understanding of these exotic quantum phases in low-dimensional systems (1D and 2D), we combine theoretical insights to identify the minimal ingredients stabilizing these states, advanced computational techniques for unbiased evaluation of their properties, and handshakes with experiments to test which theories withstand reality.

### **Summer projects:**

I envision three openings for summer research projects, each targeting a different aspect of our program:

- *Project 1: Code Development* – Build a numerical library implementing diffusion Monte Carlo to study one-dimensional quantum systems with Coulomb-like interactions. This tool addresses one of condensed matter’s most fundamental and difficult challenges: solving the many-body problem. Diffusion Monte Carlo offers an exact approach in one dimension, providing a powerful tool for benchmarking and theory development.
- *Project 2: Physical Applications* – Investigate interaction effects in the minimal model for a recently discovered superconductor, twisted WSe<sub>2</sub>, aiming to reproduce and interpret its experimentally observed phase diagram. The goal is to provide new theoretical insights into experimental signatures and propose experiments to probe the unique properties of this superconducting state.
- *Project 3: Microscopic Mechanisms* – Perform large-scale simulations across a wide range of parameters and models to uncover the conditions under which fractional Chern insulators—phases hosting anyons—emerge. Using advanced statistical analysis, extract the key microscopic features that explain their stability and leverage these insights to predict promising candidate materials for experimental realization.

### **Requirements:**

I am looking for motivated students who will have completed their third year of undergraduate studies, with a strong background in the foundations of quantum mechanics. Strong programming skills in are highly valued (Python, Julia, others....).