2024 Summer Projects

Braverman Group, Department of Physics, University of Toronto

Contact: Prof. Boris Braverman, boris.braverman@utoronto.ca

Precision measurement using disorder

Optical cavities comprised of mirrors with low absorption and scattering loss are key building blocks for precision laser stabilization and cavity quantum electrodynamics (QED) experiments. In the context of laser stabilization, Fabry-Perot cavities with a finesse of 100,000 or higher are used to measure and lock laser frequencies down to a linewidth of 1 Hz or below. Despite this exceptional performance, locking a laser to a Fabry-Perot cavity comes with drawbacks. The measurement sensitivity to changes in laser frequency is only high near the (narrow) cavity resonance, requiring the laser to already be close to the resonance in order for the laser lock to be engaged. In addition, the Fabry-Perot cavity has many identical-appearing resonances typically spaced by 1 GHz, requiring additional instrumentation to unambiguously determine the laser frequency.

A contrasting approach to laser frequency measurement and locking is to use a multipath interferometer to produce multiple intensity signals, which can be computationally inverted to extract the laser frequency. A "photon box", consisting of an enclosed space coated with low-loss optical mirrors with localized input and output ports, could in principle achieve similar precision as a Fabry-Perot cavity, but without the dynamic range and signal ambiguity limitations outlined above.

In this project, the student will study the spectral response of multipath optical interferometers, including the limit of long-duration confinement in a low-loss optical cavity. Building on current work in the research group, the student will simulate the optical response of highly multipath interferometers and measure the response of these devices in the laboratory.

Ultracold atom transport for optical clocks

Optical lattice clocks are among the most precise and accurate devices humans have ever constructed, achieving frequency measurement performance below 1 part in 10^18. In these clocks, a long-lived quantum superposition of two electronic energy levels of alkaline-earth atoms acts as the timekeeping mechanism. These clocks measure ensembles of thousands ultracold neutral atoms trapped using laser light in a region typically about 1 mm across. Further improvements in the precision of these clocks can be realized by increasing the number of atoms measured at one time, which requires enlarging the region of space in which they are confined to the scale of 10s of cm. In order to manipulate atoms over such a large region of space, it becomes necessary to transport them, while simultaneously preserving their ultracold temperatures and quantum coherences.

In this project, the student will design protocols for fast and low-loss methods to move ultracold atoms over large distances. The student will simulate the optical trapping of atoms confined in optical lattices, as a function of the transport parameters: the lattice size, speed, and acceleration.

Optimal filtering of spatial modes of light

A common challenge in laser physics is mode cleaning: increasing the coherence of a beam of light by suppressing or eliminating higher-order modes. An ideal mode filter would transmit 100% of the desired mode, and completely block all remaining modes. In the spatial domain, such an ideal filter exists: a single-mode fiber (SMF). Over a propagation distance of only a few cm, all higher-order modes can be efficiently radiated away. However, a conventional single-mode fiber is not always an option: when the target modes are higher-order transverse modes, when filtering high-intensity lasers that would damage an SMF, when working with wavelengths for which SMFs are unavailable, or when filtering temporal rather than spatial modes of light. A simple, albeit imperfect, alternative to an SMF for mode cleaning is a “spatial filter” consisting of a single aperture between a pair of lenses. More generally, one can construct a mode filter out of a sequence of arbitrarily shaped masks separated by lenses and free space.

In this project, the student will simulate the generalized version of the spatial filter and optimize its performance by varying the positions and shapes of the constituent lenses and masks to maximize the transmission of the mode of interest while suppressing all others. The student will then experimentally verify the performance of the spatial filter they designed.