Precision Measurement Using Disorder

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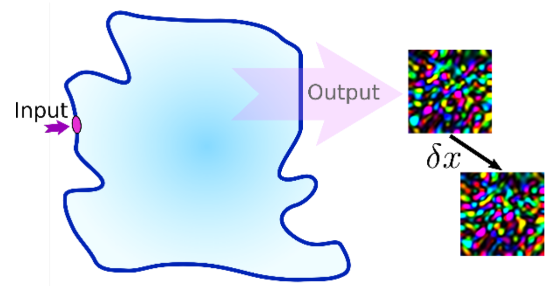
Optical cavities comprised of mirrors with low absorption and scattering loss are key building blocks for precision laser stabilization and cavity quantum electrodynamics (QED) experiments. In the context of laser stabilization, Fabry-Perot cavities with a finesse of 100,000 or higher are used to measure 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 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 highly disordered cavity with millions of spatial modes seems too complex to be useful. In this project, we study the noise patterns that emerge from this system to perform highly sensitive measurements of laser and environmental parameters.

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 [1]. 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.

[1] Facchin, M., Dholakia, K., & Bruce, G. D. (2021). Wavelength sensitivity of the speckle patterns produced by an integrating sphere. *Journal of Physics: Photonics,* 3(035005). https://doi.org/10.1088/2515-7647/ac107a