Multi-Spatial Mode Readout Of Optical Cavities For Reduced Brownian Coating Thermal Noise

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This talk will outline a new approach to mitigating Brownian coating thermal noise in optical cavities using multiple higher order TEM gaussian modes [1]. Optical cavities are the gold standard in laser frequency feedback and control but are bounded in their ultimate stability by the random $1/\sqrt{f}$ thermal motion in their thin film reflective coatings. By blending the readout signals of multiple higher order modes incident on the cavity, the effective sampling area of laser mirrors is increased. This improves the averaging of localised random thermal motion, thereby lowering the overall length noise sensed. We propose scheme where a top-hat like beam is effectively synthesised from a carefully weighted combination of signals fed back to a laser. We will present results of a theoretical study into this new sensing scheme and plans for an experimental implementation.

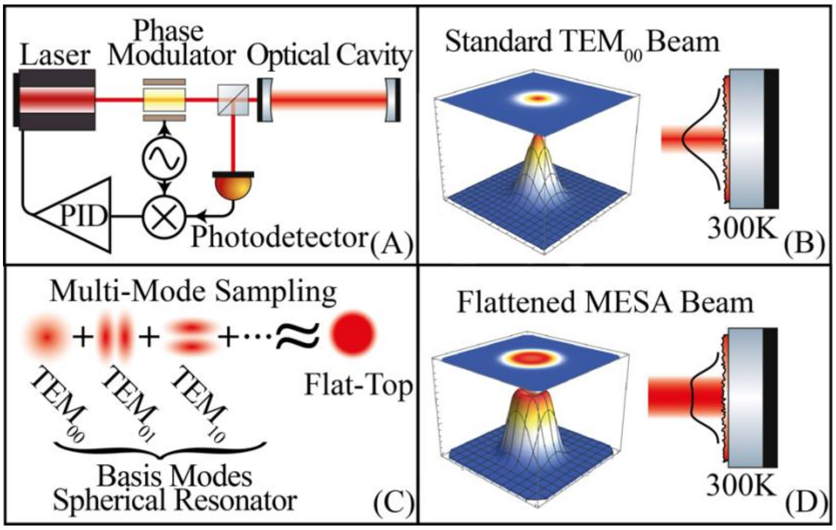

Figure 1:(A) Classic Pound-Drever-Hall locking typically implements a (B) TEM00 Gaussian Beam that is strongly weighted to the center reducing the averaging potential of beams incident on mirrors. By combining the basis set of Hermite Gaussian Modes (C) a Flat-top beam can be synthesized similar to the diffraction limited 'MESA' beam (D) that maximizes the spread of laser light on mirrors while steeply cutting off at the edges to avoid clipping.

We will show that an experimentally feasible implementation of a three-mode lock – combining modes TEM_{00}, TEM_{02}, and TEM_{20} – can reduce overall coating thermal noise by a factor of 1.6, equivalent to cooling the mirrors to 120 K. Such improvements are in addition to advancements in materials, cryogenics, cavity lengths, and shortened wavelength approaches.

We will also outline the achievable bounds on thermal noise improvements for many higher order modes (more than three) and prospects for implementation in in the laboratory.

[1] A. R. Wade and K. McKenzie, *Mirror Coating Thermal Noise Mitigation Using Multi-Spatial Mode Cavity Readout*, ArXiv:2201.09404 [Physics] (2022).