The Heisenberg Limit to Laser Coherence

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To quantify quantum optical coherence requires both the particle- and wave-natures of light. For an ideal laser, it can be thought of as the number of photons emitted into the beam with the same phase. For some 60 years, it had been believed that for a laser with an ideal output beam (described by a phase-diffusing coherent state), this number, C, was limited by the Schawlow-Townes limit to the linewidth [1]. Specifically, the S-T limit implies that the coherence C is at most of order the square of the mean photon number μ in the laser itself: C = O(μ^2). Here, assuming nothing about the laser operation except that its inputs are incoherent, and that its output is close to the ideal beam, we find the ultimate (Heisenberg) limit: C = O(μ^4) [2]. For μ large this is enormously greater. Moreover, we find a laser model that can achieve this scaling, and show that, in principle, it could be realised with familiar physical couplings [2].

[1] A. L. Schawlow and C. H. Townes, "Infrared and Optical Masers", Phys. Rev. 112, 1940-9 (1958).

[2] Travis J. Baker, Seyed N. Saadatmand, Dominic W. Berry, and Howard M. Wiseman, “The Heisenberg limit for laser coherence”, Nature Physics 17, 179–183 (2021).