No trade-off between coherence and sub-Poissonianity for Heisenberg-limited lasers

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Quantum optical coherence can be defined as the number of photons in the maximally populated mode–a definition that 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 was 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 number μ of excitations (photonic or otherwise) in the laser itself: C = O(μ^2). But in [2] it was shown, assuming nothing about the laser operation except that its inputs are incoherent, and that its output is close to the ideal beam, that the ultimate (Heisenberg) limit is C = O(μ^4). Moreover, this can be achieved, in principle, it could be realised with familiar physical couplings [2]. Here, we generalize the previous proof of this upper bound scaling by dropping the requirement that the beam photon statistics be Poissonian (i.e. that Mandel's Q parameter be equal to zero). We then show that the relation between coherence C and sub-Poissonianity (Q<0) is win-win, not a tradeoff. For both regular (non-Markovian) pumping with semi-unitary gain (which allows Q to approach -1), and Markovian pumping with optimized gain (which is limited to Q approaching -0.5), C is maximized when Q is minimized.

[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).