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Collectively-pumped superradiant laser with coherence scaling beyond the standard quantum limit

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For more than half a century, the standard quantum limit (SQL) was thought to limit the laser coherence $\mathfrak{C}$ —the number of photons emitted from the laser into the beam in one coherence time —to a scaling $\Theta(\mu^2)$, where μ is the mean number of optical-frequency excitations stored inside the laser. However, recently it has been shown [Baker et al., Nat. Phys. 17, 179 (2021)] that the Heisenberg limit —an achievable ultimate limit set by quantum mechanics for the task of producing a beam with the standard properties of a laser beam —is $\mathfrak{C} = \Theta(\mu^4)$, a quadratic enhancement. So far, proposals to demonstrate beyond-SQL scaling of $\mathfrak{C}$ have been limited to circuit QED, at microwave frequencies (i.e., a maser). Here, we propose an optical-frequency laser platform that can surpass the SQL scaling: a superradiant laser in the bad-cavity limit with feedback-controlled collective pumping. We show that the coherence can exhibit a scaling as large as $\mathfrak{C} = \Theta\left(\mu^{8/3}\right)$. Here, in the bad-cavity limit, $\mu \approx N/2$, where N is the number of superradiant atoms.

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