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Continuous lasing and atom number self-regulation of strongly coupled atoms in a high finesse cavity

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Superradiant lasers are a promising path towards realising a narrow-linewidth, high-precision and high-bandwidth active frequency reference [1]. They shift the phase memory from the optical cavity, which is subject to technical and thermal vibration noise, to an ultra-narrow optical atomic transition of an ensemble of cold atoms trapped inside the cavity. Our previous demonstration of pulsed superradiance on the mHz transition in ⁸⁷Sr [2,3] achieved a fractional Allan deviation of 6.7·10⁻¹⁶ at 1s of averaging. Moving towards continuous-wave superradiance promises to further improve the short-term frequency stability by orders of magnitude. A key challenge in realizing a cw superradiant laser is the continuous supply of cold atoms into a cavity, while staying in the collective strong coupling regime.
We demonstrate continuous loading and transport of cold ⁸⁸Sr atoms inside a ring cavity, after several stages of laser cooling and slowing. We further describe the emergence of regimes of collective continuous lasing of the atoms on the 689nm 7.5kHz transition in ⁸⁸Sr, 7x narrower than the cavity linewidth, and pumped by the cooling lasers via inversion of the motional states. The lasing is supported by self-regulation of the number of atoms inside the cavity that pins the dressed cavity frequency to a fixed value over a range of more than 3MHz of applied cavity frequency. In the process up to 80% of the original atoms are expelled from the cavity. We also show how the interplay between different cooling lasers leads to the emergence of several distinct zones of lasing.

[1] D. Meiser et al., Phys. Rev. Lett. 102, 163601 (2009).
[2] M. A. Norcia et al., Science Advances 2, e1601231 (2016)
[3] M. A. Norcia et al., PRX 8, 021036 (2018)

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