

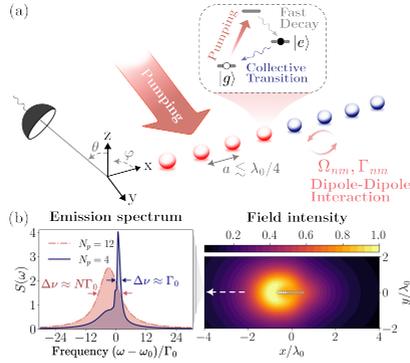
# Nanoscale Mirrorless Superradiant Lasing

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In this work, we predict collective 'free-space' lasing in a dense nanoscopic emitter arrangement where dipole-dipole coupled atomic emitters synchronize their emission and exhibit lasing behavior without the need for an optical resonator, see Fig. 1. At the example of a subwavelength-spaced linear emitter chain with varying fractions of pumped and unpumped emitters, we present a comprehensive study of this mirrorless lasing phenomenon [1]. The total radiated power transitions from subradiant suppression under weak pumping to superradiant enhancement at stronger pumping, while exhibiting directional emission confined to a narrow spatial angle. At the same time multiple independent spectral emission lines below the lasing threshold merge towards a single narrow spectral line at high pump power, see Fig. 1(b). The most substantial enhancement and line narrowing occur when a fraction of unpumped atoms is present. We show that this leads to superradiant lasing near the bare atomic frequency, making the system a promising candidate for a minimalist active optical frequency reference [2].



**Fig. 1:** (a) Schematics: A subwavelength-spaced linear chain of quantum emitters in free space. The incoherent partial pumping of the chain creates a population in the excited state from where the emitters decay and interact collectively among each other through long-range dipole-dipole interactions. (b) Right panel: Directional steady-state superradiant emission from a chain of  $N = 12$  emitters spaced by  $a/\lambda_0 = 0.1$  with  $N_p = 4$  being pumped. Left panel: The emission spectrum exhibits a narrowing linewidth for partial pumping compared to a fully pumped ensemble.

## References

- [1] A. Bychek, R. Holzinger, H. Ritsch, arXiv preprint arXiv:2505.04025 (2025)
- [2] D. Meiser, J. Ye, D. R. Carlson, M. J. Holland, Phys. Rev. Lett. 102, 163601 (2009)

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