# Design and simulation of continuously-operating superradiant laser on $^1S_0$-$^3P_0$ transition of neutral Strontium

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We report on the development towards active optical frequency standard based on superradiant laser continuously operating on the $^3P_0 - {}^1S_0$ transition of strontium atoms. A superradiant laser operates in the bad-cavity regime, where the linewidth of the cavity mode is much broader than the linewidth of the gain profile. The frequency of radiation from such a laser is robust to perturbations of the cavity, thus making it possible to create an active frequency standard similar to hydrogen masers, but operating in the optical domain.

Continuous operation of such a laser requires maintenance of the inversion, which can be achieved with the help of continuously loading atoms into an optical conveyor with magic wavelength. Such a conveyor can be created inside the ring cavity which also plays the role of the superradiance cavity[1,2]. The atoms get loaded into this cavity, and pumped into the upper lasing state, then travel over some distance along the conveyor and finally get removed. Realization of such a scheme becomes possible with the creation of a continuous source of guided ultracold Sr atoms, able to produce up to several tens of millions of $^{88}$Sr, or several millions of $^{87}$Sr atoms per second[3]. Recently we presented our approach towards realization of such a frequency standard, and reported theoretical estimation of impact of various real-life effects, such as collisions and position-dependent shift of the lasing transition[2]. Later we reported simulation of cooling the atoms and their loading into the conveyor[4].

Now we report the modern design of the optical conveyor laser, and present results of simulations of both the loading and pumping process and the generation of the superradiance signal. We include relevant real-life effects, such as temperature of the atomic ensembles, collisions, and position-dependent shifts characteristics for our setup, and present optimized operational parameters.

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[1] J.R. Cline, V.M. Schäfer, Z. Niu, D.J. Young, T.H. Yoon, and J.K. Thompson, “Continuous collective strong coupling between atoms and a high finesse optical cavity” arXiv:2211.00158v1, 2022.

[2] G. Kazakov S. Dubey, F. Famà, S. Zhou, C. Beli Silva, S.A. Schäffer, S. Bennetts, F. Schreck, "Towards an Active Optical Clock using an Optical Conveyor within a Ring Cavity," 2021 EFTF/IFCS Joint Conference, July 2021.

[3] C.-C. Chen, S. Bennetts, R. G. Escudero, B. Pasquiou, F. Schreck, “Continuous Guided Strontium Beam with High Phase-Space Density,” Phys. Rev. Applied, **12**, 044014, 2019; R. G. Escudero, C.-C. Chen, S. Bennetts, B. Pasquiou, and F. Schreck, “Steady-state magneto-optical trap of fermionic strontium on a narrow-line transition”. Phys. Rev. Research **3**, 033159, 2021.

[4] S. Dubey, G. Kazakov, S. Zhou, F. Famà, C. Beli Silva, S.A. Schäffer, S. Bennetts, B. Heizenrede, F. Schreck, "Active optical clock using optical conveyor in the ring cavity: simulation and optimization of loading the atoms," 2023 EFTF Joint Conference, May 2023.