Quantitative modeling towards continuous superradiant laser on Sr

Swadheen Dubey, M.Sc.

Under the supervision of:

Univ.Prof. Dipl.-Phys. Dr.rer.nat. Thorsten Schumm
Projektass.- Dr. Georgy Kazakov

Examiner:

Dr. Bruno Laburthe-Tolra

Abstract:

Optical clocks, with an accuracy of 10^{-18} level, are the most precise clocks ever built, and they promise a huge impact on the development of quantum technologies like atom interferometry and quantum metrology with applications in telecommunication, network synchronization and accuracy navigation through 5G networks instead of GPS. Modern-day optical clocks are *passive* frequency standards, requiring a local oscillator whose short-term stability is limited by thermal and mechanical fluctuations. To overcome this limitation, an *active* optical clock based on a superradiant laser can be developed. In this setup, atoms with population inversion on the clock transition are coupled to a resonator mode in the bad cavity regime, making the laser frequency inherently insensitive to cavity length fluctuations.

Developing such a clock based on forbidden transitions in strontium atoms presents a significant challenge, addressed by the FET-Flag project iqClock and the European Innovative Training Network MoSaiQC (Modular Systems for Advanced Integrated Quantum Clocks). At TU Wien, we, as a theoretical partner, have studied the ultimate characteristics of the active optical clocks, and performed simulations to assist our experimental partners with the design of such a clock.

In this thesis we introduce the necessary tools for studying the superradiant laser, estimate the ultimate stability which can be achieved with an active optical clock, and present a detailed feasibility study for realization of the superradiant laser on $^1S_0$-$^3P_0$ transition in neutral Sr atoms in continuous optical conveyor created inside a ring cavity. Such a configuration will be realized in the dedicated machine which is created in the University of Amsterdam. We performed simulation and optimization for different variants of continuous cooling, loading, and pumping of ultracold atoms, as well as simulation of the steady-state superradiance signal. Our analysis shows that such a machine is well-suited for the creation of a continuously operating superradiant laser using feasible experimental parameters and can serve as a benchmark for further experimental efforts.