Superradiant Active Atomic Clock at UMK

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***Summary*—We report a system of an active optical clock based on the superradiance in a bad-cavity regime that is currently under construction at UMK**

Keywords—superradiance, active optical clock

I. Introduction

One of the biggest limitations of the present generation of optical atomic clocks comes from the need of a macroscopic frequency reference, a flywheel that preserves the frequency while a new sample of ultra-cold atoms is prepared and loaded into the atomic frequency standard. This frequency reference is a laser prestabilised to the ultra-stable high-Q cavity. The cavity must be exceptionally well isolated from the environment, requiring extensive thermal insulation and vibration isolation systems.

II. METHODS/RESULTS

One of the proposed and actively developed solutions which allows omitting the external cavity limitations is the system with continuous superradiant lasing of an ensemble of atoms on the clock transition, producing light directly at the clock frequency. If superradiant lasing is sustained continuously, e.g. by replenishing the lasing ensemble from an external reservoir, there is no longer any need for bridging dead-time by an external reference oscillator. We will present a system of an active optical clock based on the superradiance in a bad-cavity regime that is currently under construction at UMK.

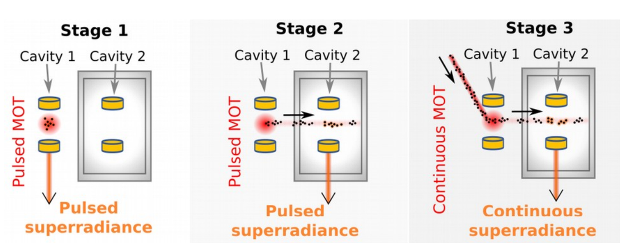

Figure 1: The mHz-transition based architecture operating on consecutive coupling of cold atomic ensembles (top view).

The UMK machine, built within the first Quantum Flagship phase by UMK with numerical support from University of Amsterdam (UvA) and Technical University of Vienna (TUW), allows for splitting the development of the continuous wave clock into three stages (see Fig. 1). Stage 1 focuses on creating a pulse of superradiant light emitted from Sr atoms on the mHz (in 87-Sr) or sub-mHz (in 88-Sr) clock transition. The hot Sr atoms will be opto-magnetically slowed down in a Zeeman slower and cooled down sequentially by blue and red MOTs. After switching off the red MOT, the atoms will be trapped in a 2D magic optical lattice, preventing collision-induced decoherence inside high-Q cavity (cavity 1 in Fig. 1), and pumped into the $^3P_0$ excited clock state. In this stage, we expand the state-of-the-art superradiance pulse demonstration of [1] to the sub-mHz line of bosonic Sr. However, the Stage-1 scheme can operate in the pulsed regime only, because the blue MOT operation quickly destroys the coherence of the superradiant ensemble. The Stages 2 and 3 change the pulsed superradiance into continuous coherent output with the help of the second cavity, where the atoms will be transferred to by a moving magic-wavelength lattice, as proposed by TUW in [2,3]. This cavity is isolated from the strong magnetic fields and MOT light, maintaining lasing during the preparation of the new atomic ensemble. In Stage 2, we focus on transferring atoms optically pumped to the excited clock state into cavity 2 in sufficient numbers to repeat the superradiant pulsed emission. In Stage 3, we will replace the Zeeman slower source by the μK-temperature Sr beam source developed by UvA. The red MOT will then operate both in pulsed or continuous mode and the excited atoms will be transferred into the cavity 2 by a conveyor belt as a sequence of overlapping packets. The new atoms will arrive before the end of the previous pulse to transfer the superradiant laser's phase and keep coherence. The output will be characterized by comparison with two passive optical Sr clocks at UMK [4].

III. Conclusions

The linewidth of a superradiant laser can be narrower than the lasing transition [5,6]. Therefore, a superradiant laser operating on a mHz clock line has the potential to be more precise than the reference oscillators used so far, which at the best reach on the order of 10 mHz [7]. A superradiant laser could thus be used as a reference oscillator with beyond state-of-the-art precision. More precise oscillators are required to profit from expected improvements in spectroscopic accuracy of standard optical clocks. Moreover, a superradiant laser can possibly be made sufficiently accurate to become a frequency standard itself, reducing the complexity of an optical clock.

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