Enhancing Optical Clock Performance with Multiple Atomic Ensembles

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The remarkable precision of optical atomic clocks enables new applications and offers sensitivity to novel and exotic physics. In this talk I will explain the motivation and operating principles of a multiplexed strontium optical lattice clock, which consists of two or more atomic ensembles of trapped, ultra-cold strontium in one vacuum chamber. This miniature clock network enables us to bypass the primary limitations to typical atomic clock comparisons and achieve new levels of precision[1].

I will present on recent experimental results in which we make use of multiple atomic ensembles to perform enhanced phase estimation and demonstrate a reduced absolute instability of an optical lattice clock[2]. I will also briefly present the results of a blinded, laboratory-based precision test of the gravitational redshift at the millimeter to centimeter scale[3]. And finally, I will discuss prospects for leveraging the level structure of strontium to convert depolarization errors into erasure errors and thereby enhance the performance of differential clock comparisons[4].

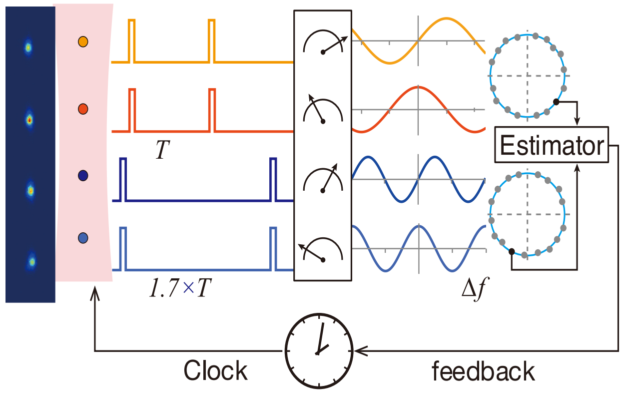

Fig. 1: We demonstrate that by splitting the atoms in an optical lattice clock up into multiple spatially resolved atomic ensembles, we can more precisely measure the frequency difference between the atomic transition and the clock laser to realize a more stable clock.

[1] X. Zheng, J. Dolde, V. Lochab, B.N. Merriman, H. Li, and S. Kolkowitz, "Differential clock comparisons with a multiplexed optical lattice clock," *Nature* **602**, 425-430 (2022).

[2] X. Zheng, J. Dolde, and S. Kolkowitz, "Reducing the instability of an optical lattice clock using multiple atomic ensembles," *Physical Review X*, **14**, 011006 (2024).

[3] X. Zheng, J. Dolde, M.C. Cambria, H.M. Lim, and S. Kolkowitz, "A lab-based test of the gravitational redshift with a miniature clock network," *Nature Communications*, **14**, 4886 (2023).

[4] P. Niroula, J. Dolde, X. Zheng, J. Bringewatt, A. Ehrenberg, K.C. Cox, J. Thompson, M.J. Gullans, S. Kolkowitz, and A.V. Gorshkov, "Quantum Sensing with Erasure Qubits," *arXiv:2310.01512* (2023).