Atomic Ensemble Engineering and In-Situ Imaging in Ytterbium Optical Lattice Clocks

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Optical lattice clocks leverage carefully engineered ensembles of neutral atoms to realize both state-of-the-art accuracy[1] and precision[2]. In this talk we present new techniques for loading ultracold atoms in programmable distributions within an optical lattice. In particular, by leveraging standard magnetic field control and clock laser light pulses we demonstrate the ability to engineer a variety of atomic distributions within 1D OLCs using the so-called 'ratchet loading' technique. Our approach has a variety of immediate applications, from preparation of extended samples with minimal atomic interaction induced frequency shifts to preparation of multiple spin states. The latter case is especially relevant to relative frequency measurement between lattice-trapped samples in the same apparatus. Recent efforts have shown that this technique can reject shared technical noise to achieve nearly 18 digits of precision in just one second of averaging[3], relying on careful engineering of atomic ensembles and elimination of differential frequency gradients. Here, we combine the technique with ratchet loaded samples. We prepare two ensembles in different motional states, enabling us to probe higher order lattice light shifts with more than an order of magnitude lower instability compared with traditional interleaved comparisons. We conclude by discussing our most recent results towards a full evaluation of lattice light shifts within Yb 1D OLCs.

[1] McGrew, W. F., et al. "Atomic clock performance enabling geodesy below the centimetre level." *Nature* 564.7734 (2018): 87-90.
[2] Oelker, E., et al. "Demonstration of 4.8×10^{-17} stability at 1 s for two independent optical clocks." *Nature Photonics* 13.10 (2019): 714-719.
[3] Bothwell, Tobias, et al. "Resolving the gravitational redshift across a millimetre-scale atomic sample." Nature 602.7897 (2022): 420-424.