Towards the next-generation of optical lattice clocks

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In the last several years, optical lattice clocks based on ytterbium have realized 10^{-18} levels (or better) in the key figures of merit of total systematic uncertainty, stability, and reproducibility [1]. Benefiting from this performance, these clocks have been deployed in optical frequency ratio measurements approaching the $5\text{x}10^{-18}$ accuracy level [2], and have been used in multi-ensemble interrogation protocols to realize new levels of frequency stability [3,4]. They have also been used to provide calibrations of International Atomic Time or other time scales, and to sensitively probe for new physics [2,5,6].

As the international community looks ahead to an optical re-definition of the SI second, it's natural to wonder how far optical clock performance will continue to improve. Here we consider techniques, strategies, and recent efforts toward realizing next-generation optical clock uncertainty and stability. The systematic uncertainty of lattice clocks is typically dominated by the BBR Stark shift or lattice light shifts, and can also be significantly impacted by ultracold collisions. Towards improved control of lattice light shifts, we report two sub-recoil cooling techniques using the narrowband clock transition. The resulting sub-uK temperatures facilitate reduced light shifts through shallow lattices, as well as a more precise determination of high-order light shift effects. Towards improved control of the BBR Stark effect, we describe a cryogenic shield with dynamic actuation, aimed at reducing the BBR shift at or below the 10^{-19} level. To mitigate pernicious ultracold collisions in the optical lattice while still allowing high atom numbers for reduced quantum projection noise, we report two techniques for realizing spatially-extended 1D optical lattices. One approach uses coherent delocalization via lattice tunneling, while the other exploits spatially-selective lattice loading using the metastable clock state. Towards improved clock stability and laser coherence, we also highlight recent efforts at laser stabilization using cryogenic sapphire optical cavities for reduced thermal noise.

Finally, if state-of-the-art optical clock performance can be realized beyond the lab, it has long been anticipated that new applications like relativistic geodesy become feasible. Alternatively, more optical frequency ratios at high accuracy can be realized, as metrologically-required for re-definition of the second. Towards these goals, we report on the construction of a transportable Yb optical lattice clock, including first measurements beyond NIST.

References

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