

# Optical lattice clock measurements at the mHz level

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The optical lattice clock has seen rapid progress since its birth one decade ago. As the performance of these frequency standards improves, so does their utility in a variety of applications, from the exploration of fundamental laws of physics to advanced synchronization and geodetic measurements. At its core, the optical lattice clock operates by interrogating an ultra-narrow optical transition in a trapped, cold atom sample consisting of thousands to millions of atoms. Consequently, these clocks have the potential for exceptional stability and timing precision. By overcoming deleterious measurement noise from the Dick effect, we demonstrate operation of a Yb optical lattice clock close to the quantum projection noise limit for a sample of 5000 lattice trapped atoms. By comparing two Yb optical lattice clocks, we directly observe a clock instability of  $1.6 \times 10^{-18}$  in 7 hours of averaging, realizing measurement of an optical frequency below the mHz level. Large atomic ensembles trapped in the magic wavelength optical lattice have the potential for even higher clock stability, and we discuss approaches to this end.

Another challenging problem facing the optical lattice clock is reducing and controlling environmental perturbations which influence the uncertainty of these standards. As a prominent example, the largest perturbative effect on most lattice clocks stems from thermal blackbody radiation which bathes the lattice trapped atoms, inducing a Stark shift on the narrowband electronic transition being probed. By surrounding the atoms in a room-temperature thermal shield, we demonstrate control of the BBR Stark shift at  $1 \times 10^{-18}$  clock uncertainty. The shield features a high-emissivity carbon-nanotube surface layer and real-time precision temperature measurement, and will be described in detail.

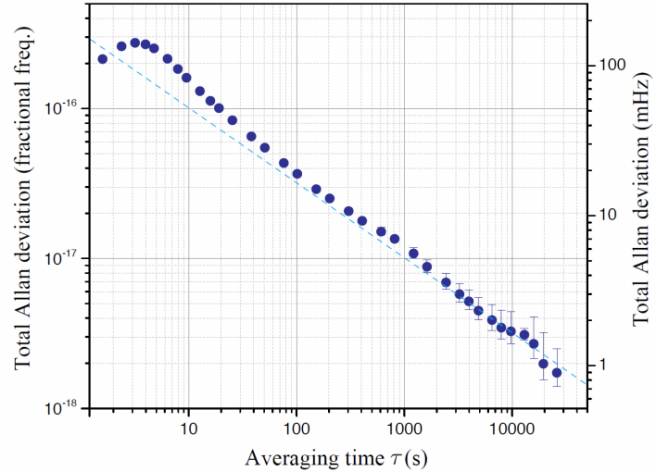


Fig. 1: Yb optical lattice clock instability, measured by comparison of two Yb lattice clocks (filled circles). Error bars give the  $1\sigma$  confidence intervals. The dashed line indicates the asymptotic instability of  $3.2 \times 10^{-16} / \sqrt{\tau}$ .