Controlling inhomogeneous broadening in a multi-ion optical clock.

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Abstract: we report a first series of experiments demonstrating the measurement and control of inhomogeneous broadening in a multi-ion optical clock using singly ionized lutetium ($^{176}Lu^{+}$). Lutetium is a unique clock candidate supporting a total of three clock transitions: a highly forbidden M1 transition at 848nm ($^1S_0$-$^3D_1$), a spin-forbidden E2 transition at 804nm ($^1S_0$-$^3D_2$), and an E2 transition at 577nm ($^1S_0$-$^1D_2$), [1,2,3]. A technique of hyperfine averaging eliminates shifts arising from the electronic angular momentum [1], which realizes an effective J=0 to J=0 transition in each case. For each clock transition the remaining systematics compare favorably to other leading clock candidates [4]. However, within the context of a multi-ion implementation, clock shifts eliminated by hyperfine averaging are a source of inhomogeneous broadening. Such broadening can diminish the effectiveness of the averaging and result in a shift of the clock transition. The main sources of broadening result from magnetic field inhomogeneity and the quadrupole shifts induced from neighboring ions. Using microwave spectroscopy within the $^3D_1$ manifold we demonstrate that the inhomogeneity can be measured and heavily suppressed. The low magnetic sensitivity of $^3D_1$ m=0 clocks states permit microwave Ramsey spectroscopy with interrogation times of several seconds. This allows high-resolution measurement of relative quadrupole shifts between ions and precise alignment of the magnetic field relative to the crystal axis to null this inhomogeneity. Additionally, microwave correlation spectroscopy on magnetic-field-sensitive states provides a high-resolution measurement of magnetic field gradients. Using these techniques we demonstrate suppression of inhomogeneity at the mHz level, limited only by the Ramsey time used. In addition, we use correlation spectroscopy on the optical transition to demonstrate atomic coherence out to ~10s within a three-ion crystal. This work demonstrates the feasibility of a multi-ion clock with $^{176}Lu^{+}$.

[1] M. D. Barrett, New J. Phys., **17** (5), 053024, (2015).
[2] Eduardo Paez, et al. Phys. Rev. A, **93** (4), 042112, (2016).
[3] R. Kaewuam, A. Roy, T. R. Tan, K. J. Arnold, and M. D. Barrett, J. Mod. Opt., **65** (5-6), 592, (2017).
[4] K. J. Arnold, R. Kaewuam, A. Roy, T. R. Tan, and M. D. Barrett, Nat. Comm., **9**, 1650, (2018).