Quantum engineering in optical lattice clocks

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Background – Atomic clocks use the indistinguishability of atoms and our ability to experimentally prepare atoms in specific quantum states to create clocks with remarkable accuracy and stability. An optical lattice clock uses neutral atoms held during clock spectroscopy in a `magic'-frequency optical lattice trap [1, 2]. This mimics the near perturbation-free environment of a single ion clock, but for 10^4-10^5 more atoms, promising short-term frequency instabilities at the 10^{-18} fractional level. Beyond timing and synchronisation, this precision offers utility in sensing the Earth's gravitational potential at the 1 cm level. Lattice clocks present possibilities in numerous precision measurement applications e.g. to determine local gravity [3], perform relativistic geodesy, form the basis of extremely narrow linewidth lasers [4], provide a route towards quantum computing [5], and in searches for possible time-variation of fundamental constants [6], and dark matter [7].

Project – The Sr optical lattice clock system at NPL [8] has a demonstrated instability of $1 \times 10^{-15}\, \tau^{-1/2}$ (τ is the averaging time) and an inaccuracy of $<5 \times 10^{-17}$. To reach a target 1×10^{-18} inaccuracy, all relevant perturbing interactions must be understood, measured, and controlled. These are broadly grouped into: atom-atom interactions, e.g. cold collisions and background gas collisions; atom-electromagnetic interactions, e.g. Stark shifts from the lattice trap, clock probe, and blackbody radiation; Zeeman shifts from stray magnetic fields. A low instability is key to reaching a low inaccuracy of the clock. Despite the use of ultra-stable laser systems with sub-hertz linewidths, lattice clock stability is currently limited by an aliasing of the periodically sampled laser noise (known as the Dick effect) and not quantum-projection noise.

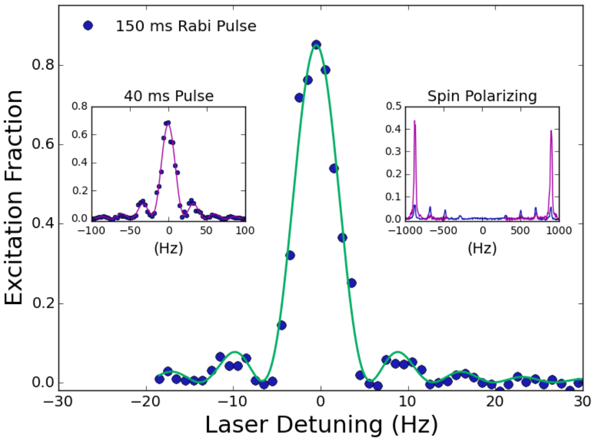

Figure 1. Coherent Rabi spectroscopy of the Sr clock transition for 40 ms (inset-left) and 150 ms (main) π-pulse, and spectroscopy of m_F states with and without spin-polarising (inset right).

Masters Project – Your project will focus on quantum-engineered optical interrogation methods to minimise perturbation of the clock transition frequency in a bosonic Sr optical lattice clock, towards a magnetic field-insensitive clock. Interrogation techniques similar to ref [9] will be applied to coherent multi-photon Raman excitation schemes used to access the forbidden $^1S_0$ - $^3P_0$ clock transition in ^{88}Sr.

PhD Project – You will build on previous work to establish a Dick-free optical lattice clock by interleaving two systems, and to realise for the first time a QPN limited lattice clock instability. In this regime we will study techniques to further enhance clock stability by exploiting quantum correlations (e.g., spin-squeezed states) by cavity-enhanced quantum non-demolition measurements and an alternative Rydberg dressing technique [10]. The work will involve developing new cold-atom systems, stabilised lasers, and contribution to local and international clock comparison measurement campaigns.

References:

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