Rydberg spin-squeezing for a strontium optical lattice clock

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We propose a new technique[1] for achieving high levels of spin-squeezing in strontium optical lattice clocks using the long-range Van der Waals interactions between high-lying Rydberg states. We report on our experimental progress towards demonstrating this method.

Optical lattice frequency standards have demonstrated world leading fractional frequency stabilities and uncertainties[2]. The fractional frequency stability is currently limited by the Dick effect, and the best clocks demonstrate stabilities within a factor of ~3 of the quantum projection noise (QPN) limit[2,3]. Interleaved interrogation methods have been proposed to lower the Dick effect beyond the QPN limit and may soon be realized[3].

Spin-squeezing can be used to overcome the QPN limit[1,4,5]. In our protocol spin-squeezing is achieved by using only one additional laser at 317 nm to off-resonantly couple the Rydberg state to the upper clock state. This introduces switchable, long-range, long-lived interactions between the atoms, see Fig. 1. Detailed calculations show that over 10 dB of squeezing can be achieved in timescales as short as a few microseconds without significantly affecting the subsequent clock interrogation[1].

We have built a narrow-linewidth UV laser system with greater than 200 mW output power, and combined with our cold Sr Rydberg apparatus we will demonstrate this Rydberg dressing and spin-squeezing technique[6].

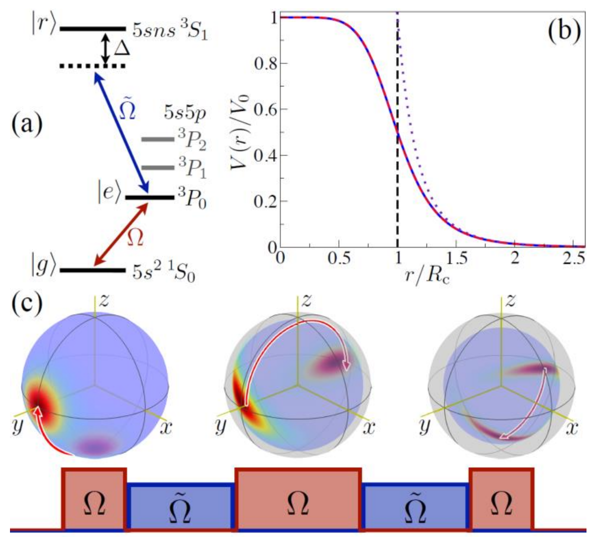

Fig. 1: (a) Energy level diagram for Sr. The upper clock state $|e\rangle$ is off-resonantly coupled to a high-lying Rydberg state $|r\rangle$. (b) The potential resembles the van der Waals interaction $\sim 1/r^6$ (dotted curve) at large separation r, but saturates below a critical distance R_c (vertical dashed line). (c) Spin-echo type squeezing protocol, consisting of linear spin rotations around the x-axis and nonlinear rotations around the z-axis, driven by the two laser fields. The resulting evolution of the total spin is illustrated on a generalized Bloch sphere. For clock operation, this spin-echo sequence is followed by a conventional Rabi or Ramsey scheme.

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