Single-photon quantum memories and optical control of nuclear spins in hot atomic vapors

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Atomic vapor cells have recently gained renewed interest as a robust and compact platform for quantum science and technology. Powerful techniques for optical quantum control are being developed, opening up many new opportunities beyond the classical application as frequency standards. In this talk I will give an overview of our vapor cell activities in Basel, focused on single-photon quantum memories and quantum sensing with electronic and nuclear spins.

Quantum memories for single photons based on atomic vapor cells offer high intrinsic efficiencies and long storage times in a technologically simple setup. To turn them into useful components for quantum networks, some challenges remain, such as reducing read-out noise, increasing end-to-end efficiency, and resolving the bandwidth-mismatch to solid-state single photon sources. We have developed a broadband optical quantum memory with on-demand storage and retrieval on the D1 line of a hot Rb vapor [1] and a compatible SPDC single photon source with bandwidth on the order of 100s of MHz and 50% heralding efficiency [2]. Recent improvements to the memory scheme and the source allowed us to significantly reduce noise, extend lifetime and improve the reliability of operation. We now report the logical combination of these experiments, the storage of heralded single photons from the SPDC source in the atomic memory, and show non-classical $g^{(2)}$ of the retrieved photons. By combining high bandwidth and low-noise single-photon operation, our memory could be used to synchronize probabilistic single-photon sources or photonic quantum gates.

The nuclear spin of Helium-3 atoms in a room-temperature gas is a very well isolated quantum system featuring record-long coherence times of up to several days. It is used in a variety of applications ranging from magnetometry and gyroscopes to magnetic resonance imaging and precision tests of fundamental physics. While the exceptional isolation of Helium-3 nuclear spins ensures long coherence times, it renders measurement and control difficult. We report first experiments towards optical quantum control of Helium-3 nuclear spins. We make use of metastability-exchange collisions to mediate an effective interaction between the nuclear spins and light, which allows us to read out the coherent nuclear spin dynamics with an optical Faraday measurement. Reaching quantum-noise limited detection and increasing the coupling strength will allow us to prepare non-classical nuclear spin states via QND measurement [3].

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[3] A. Serafin, M. Fadel, P. Treutlein, and A. Sinatra, *Nuclear spin squeezing in Helium-3 by continuous quantum nondemolition measurement*, arXiv:2012.07216 (2020).