Towards satellite-suited noise-free quantum memories

Luisa Esguerra[1,2], Leon Meßner[1,2], Elizabeth Robertson[1,2], Mustafa Gündoğan[1,3], Janik Wolters[1,2]
[1] German Aerospace Center (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany.
[2] TU Berlin, Institute for Optics and Atomic Physics, Hardenbergstr. 36, 10623 Berlin, Germany.
[3] Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, Berlin 12489, Germany.

The use of satellites equipped with quantum memories as transmission links between the nodes of a quantum network could push the current distance limit for quantum key distribution QKD [1]. Atomic vapours constitute an ideal system, since they do not pose the need to use strong magnetic fields or large cryogenic systems. We realise a satellite-suited quantum memory in Caesium vapour, based on electromagnetically induced transparency (EIT) on the D1 line. Here, the Caesium atoms act as three-level Lambda systems (inset Fig.1a). A signal/control laser configuration on the $|g\rangle$-$|e\rangle$ and the $|s\rangle$-$|e\rangle$ transitions respectively, is used in order to transfer the incoming signal pulse onto a spatially-distributed, long-lived, coherent superposition of the states $|g\rangle$ and $|s\rangle$, referred to as a spin wave [2].

Using this technique we demonstrate the storage of a signal pulse in the memory and its retrieval after up to $3\,\mu$s (Fig.1a). Current memory efficiencies are $\eta_{\text{Memory}} \approx 25\%$. Straightforward technological improvements will allow us to further enhance these efficiencies. Furthermore, the prevalent noise source in this memory is collision-induced fluorescence close to the signal laser frequency (Fig.1b). We obtain a signal-to-noise level of unity for input signal pulses containing $\bar{\mu}_1 = 0.013$ photons, which to our knowledge is significantly lower than in state-of-the-art EIT-based warm vapour memories. In future work we plan to minimise the existing noise while boosting the memory efficiency, and to pair our memory with a single-photon source [3,4] in order to achieve low-noise storage of single photons.

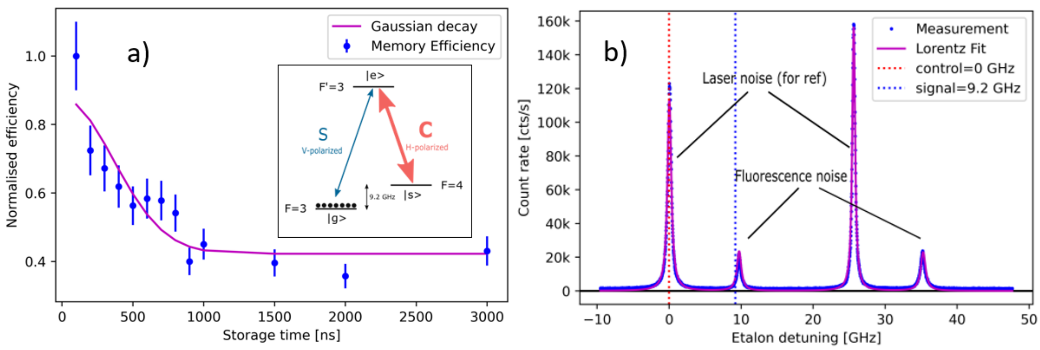

Figure 1. **a)** Memory efficiency measured as a function of storage time. As a visual guide, a Gaussian decay is plotted. Inset: three-level Lambda system with signal laser S on the $|g\rangle$-$|e\rangle$, and control laser C on the $|s\rangle$-$|e\rangle$ transitions of the Cs D1 line. **b)** Noise detected on a single-photon counter, while scanning the frequency of one of the etalons used for spectral filtering over two spectral ranges ($f_{\text{FSR}} = 25.6\,\text{GHz}$), while keeping another etalon on resonance with the signal frequency. Large peaks at 0 and 25.6 GHz detuning correspond to leaked control-laser contributions, and small peaks are fluorescence noise near the signal frequency. Reference vertical dashed lines show the control (red) and signal (blue) laser frequencies.

[1] M. Gündoğan, J. S. Sidhu, V. Henderson, L. Mazzarella, J. Wolters, D.K.L. Oi, M. Krutzik, "Space-borne quantum memories for global quantum communication", arXiv:2006.10636 (2020).
[2] J. Wolters, G. Buser, A. Horsley, L. Béguin, A. Jöckel, J.P. Jahn, R.J. Warburton, and P. Treutlein, "Simple Atomic Quantum Memory Suitable for Semiconductor Quantum Dot Single Photons", PRL **119**, 060502 (2017).
[3] R. Mottola, G. Buser, C. Müller, T. Kroh, A. Ahlrichs, S. Ramelow, O. Benson, P. Treutlein, J. Wolters, "An efficient, tunable, and robust source of narrow-band photon pairs at the ^{87}Rb D1 line", Opt. Express **28**, 3159-3170 (2020).
[4] T. Kroh, J. Wolters, A. Ahlrichs, A.W. Schell, A. Thoma, S. Reitzenstein, J.S. Wildmann, E. Zallo, R. Trotta, A. Rastelli, O.G. Schmidt, O. Benson, "Slow and fast single photons from a quantum dot interacting with the excited state hyperfine structure of the Cesium D1-line", Sci Rep **9**, 13728 (2019).