High-capacity, warm atomic memory operating at a single-photon-level storing up 120 spatial modes

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Quantum memories hold promise to achieve scalable quantum communication networks [1] and scalable linear quantum computing (QC) systems [2]. Instead of using one memory for one qubit, the ability to store and readout multiple photon modes from a single memory can bring a significant simplification of future quantum devices and in principle it may allow QC inside a single memory [3]. Nevertheless recent demonstration of multimode memories in time-frequency [4] and spatial [5] domain have not reached a single photon-level prerequisite for QC schemes.

Here we report the first to our knowledge experimental demonstration of high-capacity, spatially multimode warm atomic memory operating at the single-photon-level. Our implementation, sketched in Fig. 1, relying on spontaneous write-in inside the memory overcomes the need of matching the heralded photons from the external source with the atoms [6]. Instead, the write-in is heralded by the Stokes scattered photons which are generated inside the memory [7]. The super-efficient triple filtration system provides high signal to noise ratio and the ultra-low-noise intensified sCMOS camera sensitive to single photons allows us to count scattered photons with photon-number and spatial resolution [8].

We present in Fig. 2 that the photons stored up to several microsecond, after retrieval, demonstrate excellent correlations with their Stokes heralds. Specifically, a Stokes photon detected at the scattering angle $\theta^{(S)}$ heralds the write-in of an excitation in a one atomic spin-wave, which can be read-out yielding on-demand generation of an anti-Stokes photon within a known narrow angle $\theta^{(AS)} = \theta^{(S)} \pm \sigma/\sqrt{2}$. As presented in Fig. 2(c) we achieved storage and retrieval of up to 120 modes, which is the first demonstration of single-photon-level correlations between heralding and retrieved photons in the spatially-multimode regime. Our results open up new perspectives for implementations of inside-memory quantum protocols in warm atomic systems.

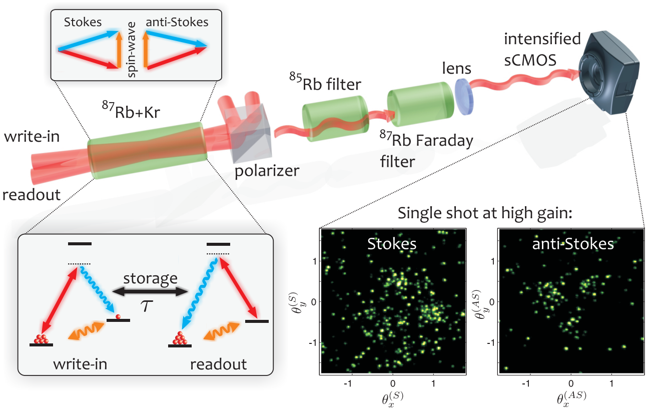

Figure 1. The scheme of the experimental setup for the spatially-multimode Raman memory, using 75°C rubidium-87 vapor in 1 torr of the krypton buffer gas, equipped with the single-photon-sensitive intensified sCMOS camera placed in the far field. The Stokes scattered photon heralds a spontaneous write-in of a spin-wave excitation which can be read-out on demand in the anti-Stokes process. The phase matching condition (inset) impose correlations between conjugate directions of Stokes and anti-Stokes photons which can be seen even in a single shot by ramping up the Raman gain and populating many spatial modes simultaneously.

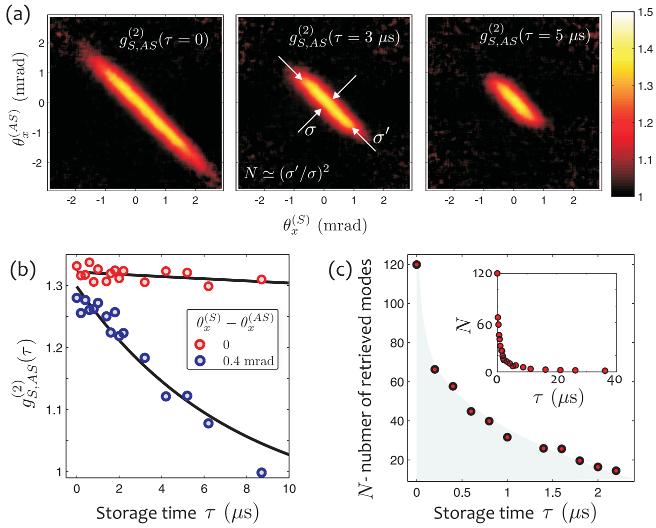

Figure 2. (a) Maps of $g^{(2)}_{S,AS}$ cross-correlation between Stokes and anti-Stokes photons for increasing storage times. Photons are counted in small circular regions of 0.02 mrad^2 around directions $\theta_x^{(S)}$, $\theta_x^{(AS)}$ and their maximum mean number do not exceed $\langle n \rangle < 0.5$. (b) $g^{(2)}_{S,AS}$ versus storage time for two exemplary pair of directions: laying on-axis and off-axis. (c) The ratio of widths of the correlation maps in the anti-diagonal σ', and diagonal σ directions yield the estimated number of retrieved modes $N \simeq (\sigma'/\sigma)^2$.

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