Measurement-induced nonlocal entanglement in a hot, spin-exchange dominated atomic vapour

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Hot alkali vapours have surprising coherence properties, most notably the simultaneous high densities and long coherence times observed in the SERF regime. The advantages of this mode of operation have been realized in magnetometry, gyroscopy, and searches for physics beyond the standard model. Here we note that the same properties make SERF-regime vapours very attractive for quantum non-demolition (QND) measurements, with well-known applications including entanglement generation, quantum memory, quantum teleportation, and quantum simulation. To date, there is however no experimental evidence that SERF-regime vapours can support quantum correlations such as spin squeezing, and quantum statistical models used at low densities are not directly applicable. With this as background, we report entanglement generation by optical QND measurement in a SERF-regime ^{87}Rb vapour. We continuously probe an un-pumped ensemble precessing in response to a field along the $(1, 1, 1)$ direction (relative to the probe), allowing us to collect information on all three spin components. Using the Bayesian signal-recovery technique of Kalman filtering [1] (see poster by Ricardo Jimenez-Martinez), we reconstruct the evolving spin state. The precision of the reconstruction is such that the uncertainty of the three spin components drops below the standard quantum limit, indicating spin squeezing and generation of a non-classical state known as a "macroscopic spin singlet." Moreover, through spin-squeezing inequalities, it is possible to identify the number of atoms participating in entangled states, which is at least 2.3×10^{13}, a few orders of magnitude beyond previous records. Finally, by applying field gradients, we demonstrate that the entanglement is generated among atoms with separations of up to several millimeters, confirming the ability of QND measurement to remotely generate entanglement in SERF systems [2].

[1] R. Jiménez-Martínez, J. Kołodyński, C. Troullinou, V. G. Lucivero, J. Kong, and M. W. Mitchell, Signal tracking beyond the time resolution of an atomic sensor by Kalman filtering, Phys. Rev. Lett. **120**, 040503 (2018)
[2] J. Kong, R. Jiménez-Martínez, C. Troullinou, V. G. Lucivero, & M. W. Mitchell, Measurement-induced nonlocal entanglement in a hot, strongly-interacting atomic system, arXiv:1804.07818 (2018)