Hybrid entanglement between hot atoms and a cryogenic membrane oscillator

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We demonstrate first experimental generation and certification of entanglement between a hot atomic vapor and a cryogenically cooled mechanical membrane oscillator. The interaction between systems is facilitated by light, that subsequently interacts with the atoms via Faraday rotation, and is then reflected off the cavity which contains a semi-reflective membrane. Entanglement is achieved as both systems operate near their respective ground states. The atoms are pumped to a maximal m_F state and we consider them a *negative-mass* oscillator, as the collective spin and magnetic field are oriented in the same way. Paraffin coating and micro-channel shaped cell allow optimized quantum cooperativity. The phononic-crystal membrane is pre-cooled in liquid Helium, and then laser cooled close to its motional ground state.

As the light passes through both systems, the which-system information is effectievly erased and a homodyne measurement projects both systems onto an EPR-type entangled state with variance V_c 20% below a classical limit. We use a Wiener filter to optimally estimate the trajectory of the entangled pair, pointing to the possibility of completly noiseless quantum tracking.

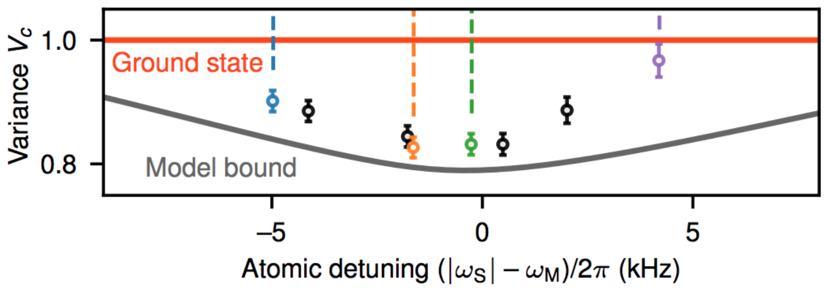

Figure 1. Conditional variance V_c as function of frequency detuning between the atomic spins ω_S and the mechanical membrane ω_M. We observe that thanks to optimal Wiener-filter estimation, we may condtionally entangle the system even if they are detuned by more than their linewidths.

[1] R. A. Thomas, M. Parniak, C. Østfeldt, C. B. Møller, C. Bærentsen, Y. Tsaturyan, A. Schliesser, J. Appel, E. Zeuthen & E. S. Polzik, Entanglement between distant macroscopic mechanical and spin systems, Nature Physics (2020).
[2] C. B. Møller, R. A. Thomas, G. Vasilakis, E. Zeuthen, Y. Tsaturyan, M. Balabas, K. Jensen, A. Schliesser, K. & Eugene S. Polzik, Quantum back-action-evading measurement of motion in a negative mass reference frame, Nature 547, 191-195 (2017)