Feedback cooling atomic gases to quantum degeneracy

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Degenerate quantum atomic gases are instrumental in advancing many-body quantum physics [1] and underpin emerging precision sensing technologies [2]. Despite substantial achievements in ultracold atomic physics, all state-of-the-art experiments achieve quantum degeneracy using lossy evaporative cooling techniques largely unchanged from those used in the first realisations of Bose-Einstein condensates (BECs) nearly three decades ago. We propose an entirely new, low-loss method of cooling thermal clouds of neutral alkali atoms to quantum degeneracy by optical feedback control. We report recent results [3] in which we model a Bose gas of ^{87}Rb atoms cooled by a simple closed-loop feedback control, showing that it can cool a thermal cloud of condensate fraction $(3.5 \pm 0.2)\%$ to $(92.1 \pm 0.5)\%$ pure condensate. We demonstrate robustness to realistic experimental constraints including limited imaging and control resolution, control loop lag, limited quantum efficiency, electronic noise, and spontaneous emission. We also present a high-level discussion of novel full-field quantum simulation techniques developed for this study. Finally, we present recent advances in highly-optimised feedback protocols derived from an analytic model, comparing the performance of optimised controls to the first-generation control employed in Ref. [3].

[1] C. Gross and I. Bloch, *Science.* 357(6355):995-1001 (2017).

[2] S. Szigeti, O. Hosten and S. Haine, *Appl. Phys. Lett.* 118(14):140501 (2021).

[3] M. Goh, Z. Mehdi, R. Taylor, R. Thomas, A. Bradley, M. Hush, J. Hope and S. Szigeti, *arXiv preprint* 2206.05069 (2022).