A New Approach to Generate a CW Atom Laser

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So far Bose-Einstein condensates and atom lasers have only been demonstrated as the products of a time sequential, pulsed cooling sequence. For applications such as next-generation atomic clocks, superradiant lasers or atom interferometers for gravitational wave detection, a steady-state source of quantum degenerate atoms offers great advantages.

However, the goal of producing a steady-state BEC or steady-state atom laser has long been thwarted by the incompatibility of laser cooling with evaporative cooling.

In this work, we implement two novel laser-based cooling schemes. The first method allows us to generate a steady-state strontium sample with a phase-space density approaching quantum degeneracy ($PSD \sim 1$), a critical step in our innovative approach to produce a steady-state atom laser. The second is a new Sisyphus cooling method not relying on radiation pressure [1], particularly applicable to laser cool molecules and exotic species such as antihydrogen.

Our first scheme demonstrates unprecedented phase-space densities by combining several ingredients. Initially, a spatially distributed architecture cools atoms using first the broad 30-MHz and then the narrow 7.4-kHz strontium transitions in two spatially separated regions [2]. We then optically guide and transport these atoms to a region with very little resonant laser cooling light. Finally, we protect this region using a “transparency beam” that Stark shifts atoms’ energy levels out of resonance from the narrow cooling transition [3]. We demonstrate steady-state samples with a phase space density of 1, well on the way to degeneracy and ultimately the source for a steady-state atom laser.

The second laser cooling method we demonstrate [1] was first proposed for laser cooling antihydrogen. Atoms are selectively excited to an electronic state subjected to a spatially-varying Stark shift from an optical lattice potential. Atoms decelerate solely by climbing the potential in the excited state, before the ensuing spontaneous decay, completing one Sisyphus cycle. We demonstrate that this new technique not only eliminates many of the constraints and limitations of traditional radiation pressure based approaches, it does so while delivering a similar atom number with lower temperatures. This method can be instrumental in bringing new exotic species and molecules to the ultracold regime.

References