AEgIS: Perspectives opened by positronium laser cooling on precision spectroscopy

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Positronium (Ps) is the lightest atomic system, comprising solely an electron and a positron[1]. Extensive research has focused on Ps due to its unique characteristics as a matter-antimatter system of leptons. Previous Ps experiments relied on formation processes, leading to clouds with a substantial velocity distribution, typically in the order of several 10^4 m/s[2,3]. This velocity distribution limits spectroscopy precision due to significant Doppler broadening of transition lines[4]. The concept of laser cooling for Ps dates back to 1988, Despite considerable efforts, experimental achievement of Ps laser cooling has remained elusive[5].

We present the successful laser cooling of a significant portion of positronium in free-flight by strongly saturating the 1^3S–2^3P transition using a broadband, long-pulsed 243 nm alexandrite laser. We observe two laser-induced effects: an increase in ground state atoms after Ps resides in the long-lived 2^3P states and a one-dimensional Doppler cooling effect, reducing the cloud temperature from 380(20) K to 170(20) K. We demonstrate a 58(9)% enhancement in the coldest Ps fraction.

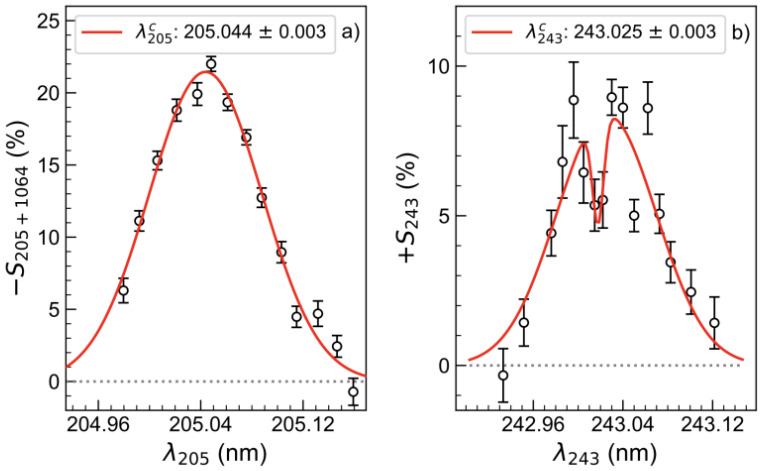

Fig. 1: Ps velocity distribution measured by Single-Shot Positron Annihilation Lifetime Spectroscopy. a) Transverse Doppler profile measured by two-photon resonant ionization. A Gaussian fit yields a Ps rms-velocity of $5.3(2) \times 10^4$ m/s. b) Velocity-resolved increase in the number of ground state Ps atoms induced by the 243 nm transitory excitation to the 2^3P level. A 2-Gaussian fit yields a Ps rms-velocity of $4.9(4) \times 10^4$ m/s.

Cooling the positronium ensemble opens new opportunities for accurate spectroscopy. Accurate determination of the optical transitions' frequencies critically tests quantum electrodynamics. Understanding quantum effects on optical transitions could facilitate transferring this knowledge to more complex atoms with narrow optical transitions, enhancing the accuracy of optical atomic clocks by incorporating higher-order corrections from quantum electrodynamics.

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