Doctoral Program in Metrology, XXXVIII cycle
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Thesis title: Advancing Optical Lattice Clocks: Accurate Measurements on a Bosonic System and Development of a Hybrid Cavity-Lattice Clock

Abstract

This thesis presents advances on the bosonic ^{88}Sr optical lattice clock operated at INRiM, the Italian National Metrology Institute. Exploiting the recently upgraded clock laser frequency stability, and after realizing several improvements within the existing clock apparatus, this work presents a detailed characterization of the key systematic shifts affecting the clock, such as the quadratic Zeeman shift and the clock laser light shift, which are notoriously relevant for bosonic clocks. The lattice light AC Stark shift and other key systematics are also evaluated. The total fractional frequency uncertainty is evaluated to be 3.9×10^{-16}, representing a nearly two orders of magnitude improvement with respect to the previous clock uncertainty budget assessment.

Beyond its metrological evaluation, the optical lattice clock is used to investigate the interactions properties of ^{88}Sr by measuring collisional losses, decoherence, and density dependent frequency shifts in both one and two-dimensional optical lattices. Through these measurements, this work offers novel insights on the elastic interaction properties between excited-excited and ground-excited ^{88}Sr atoms, which allowed to provide estimates of the strength and sign of the relevant scattering parameters.

In the final part, this thesis introduces the design and mechanical implementation of a cavity-enhanced extension of the optical lattice clock, which represents the future direction towards INRiM strontium clock is evolving to. The proposed system combines a magic-wavelength optical lattice with a cavity-QED architecture targeting strong, homogeneous, and collective coupling on the $^1S_0 \leftrightarrow ^3P_1$ intercombination transition of strontium. This configuration enables non-destructive measurement schemes and the generation of collective atomic states, such as spin-squeezed states, with the potential to reduce quantum projection noise and improve clock stability. Furthermore, the system also provides a platform for exploring collective light-matter phenomena, such as superradiant emission on both the red cooling and clock transitions.