Engineering quantum states in hybrid atom-cavity coupled systems for quantum enhanced metrology

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Abstract

The interplay between quantized photonic fields and collective atomic states offers a powerful avenue to push optical clocks beyond classical performance limits, ushering in a new generation of quantum-enhanced timekeeping. Current state-of-the-art optical clocks face limitations from thermal noise in local laser oscillators and quantum projection noise during destructive measurements.

By leveraging cavity-coupled atomic ensembles, this research aims to overcome these barriers. Through quantum backaction, such systems can produce quantum-correlated collective states (e.g., spin-squeezed states) that surpass classical shot-noise limits [1]. Furthermore, strongly coupled ensembles can exhibit superradiance, generating laser radiation with spectral purity beyond the technical constraints of cavity coherence, paving the way for "active optical masers."

INRIM is advancing this frontier with a novel optical frequency standard based on a hybrid atom-cavity system [2]. This project will experimentally study such a system, where ultracold strontium atoms are coupled to a high-finesse optical resonator designed to operate at both the intercombination transition (689 nm) and the clock transition (698 nm). The experimental setup includes developing ultra-stable laser sources and techniques for spectral purity transfer [3].

The candidate will tackle challenges in ultra-cold atomic physics and high-finesse resonator coupling, investigating non-linear spectroscopic features of cavity QED. These phenomena arise from the interplay between light and matter in the strong-coupling regime and enable the generation of non-classical light-atom states. The outcomes will have significant implications for quantum matter, quantum information, and quantum-enhanced metrology and sensing.

References

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