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Continuous-Wave Superradiant Laser

Clocks are vital components for many applications in our modern society, such as the operation of GPS and the synchronization of telecommunication networks. Clocks are also used as powerful tools to bolster our investigations of physical phenomena, such as the detection of low-frequency gravitational waves, the search for dark matter or for variations of fundamental constants.

Optical clocks operate by trapping and cooling a sample of ultracold atoms, then measuring the energy difference between atomic levels with a probe laser that addresses a very narrow optical transition. Thanks to decades of developments, these clocks are some of the most stable clocks ever built, reaching relative accuracies of about 10^{-19} [1]. One major limitation of current state-of-the-art ultracold-atom optical clocks is the need for an exquisitely stable frequency reference. Such reference is acting as a fly-wheel during the time between two probe-laser interrogations, when the ultracold-atom sample needs to be renewed. This reference is composed of a laser stabilized to a Fabry-Perot optical cavity that needs to be isolated from external perturbations. Keeping stable the length of this cavity is technologically extremely challenging, requiring for example to cool this cavity to cryogenic temperatures.

Recently, a solution has been proposed to bypass the need for a perfectly stable cavity [2]. This prescribes to turn the clock from passive to active: instead of shining very stable laser light onto ultracold atoms, the clock would operate by letting the atoms themselves emit light. Much like the working principle of a laser, ultracold atoms would be prepared in an excited state then placed between two mirrors forming a cavity. The atoms will coherently emit light in the cavity mode, but its frequency will mostly be set by the atoms, and not by the, here relatively unstable, cavity. Unlike a laser, the light stability and coherence will be set by a collective synchronization of the atomic dipoles with each other, a process called superradiance [3]. The development of such scheme could mark the advent of a new generation of clocks.

In the team Magnetic Quantum Gases (GQM) of the *Laboratoire de Physique des Lasers*, we are building a prototype for such an active ultracold-atom optical clock. In particular, we want to focus on tackling the unresolved issue of operating the clock in a continuous manner, meaning the emitted light will no longer form a burst but rather a fully continuous wave, thus harnessing the full potential of the clock [4]. This will be done using an effusive beam of strontium atoms inside a high-vacuum chamber, that we will slow, cool, and guide up to the mode of an optical cavity. There we will make atoms emit light in a superradiant fashion and will investigate the properties of the light produced by this superradiant laser. We are particularly interested in understanding the dynamics of the establishment of coherence and in probing the many-body entanglement that can occur between all atomic emitters.

The construction of this new experiment is underway, and the future PhD student will be in charge of ensuring its completion, of observing the first signs of superradiant emission, and of investigating the light properties. They will be looking at superradiance phenomenon and quantum correlations between emitters, and they will benchmark the potential of this new scheme for the next generation of clocks.

Group webpage and recent publications: http://www-lpl.univ-paris13.fr/gqm/

Keywords: Laser physics, superradiance, atomic physics, ultracold atoms, laser cooling, quantum correlations, active optical clocks.

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