Stefano Condio

Ciclo XXXVII

Corso di Dottorato in Metrologia

Politecnico di Torino

Title:

Operation and optical frequency comparisons with an ytterbium optical lattice clock

ABSTRACT

Optical clocks represent the state of the art in frequency metrology. They have widely surpassed microwave frequency standards, achieving unprecedented levels of accuracy and stability. This advancement pushes the limits of fundamental research, enabling tests of variations in fundamental constants, detection of dark matter, and explorations in general relativity. For all these reasons, optical frequency standards are considered the strongest candidate to replace Cesium clocks for a new definition of the second in the International System of Units. The mandatory criteria for a new definition have been established in a roadmap that guides international efforts toward their fulfillment. These requirements include absolute frequency measurements of optical transitions, frequency ratios between optical clocks, and regular contributions to timescale generation. This thesis aims to explore the potential and reliability of optical clocks for a new definition of the second, addressing the main challenges along this path.

My Ph.D. research mainly focused on the operation and improvement of the IT-Yb1 optical lattice clock, developed at INRiM and based on neutral 171Yb atoms. Its fractional systematic uncertainty has been characterized at the level of $1.9 \times 10{-}17$ with an instability of $2 \times 10{-}15$ at 1 s. I will present several improvements I implemented on this atomic clock, including enhancing its automation capabilities to facilitate unattended measurements and optimizing the atomic state preparation phase. Specifically, these improvements involved optimizing the spin polarization process and implementing a sideband cooling scheme on the clock transition to reduce the temperature of the atomic ensemble.

I will describe the main metrological results obtained during these years. These include two absolute frequency measurements of the ytterbium clock transition, conducted both locally and remotely for more than 900 hours. My work also involved participation in two international frequency comparison campaigns, connecting up to 11 optical clocks across Europe via fiber link and GNSS satellite, where I contributed operating the clock continuously to collect data for more than one month. In addition,

I will present IT-Yb1's participation in the calibration of Coordinated Universal Time (UTC) for 16 consecutive months. I will also discuss the generation of a local timescale, steered solely by data from the INRiM ytterbium clock for over a year.

I will also describe my activities during a secondment at the University of Amsterdam, where I contributed to the development of an active optical clock based on superradiance. This technology represents a promising future advancement in optical frequency metrology. My specific focus was on the design and characterization of a transfer cavity used to transfer spectral purity from a stable reference to the lattice laser employed in the clock.

This work directly contributes to the ongoing advancement of optical atomic clock technology and its impact on a new definition of the second.