Towards a Transportable Yb Lattice Clock at SYRTE

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***Summary*—We describe the design of a transportable optical lattice clock based on neutral ytterbium at SYRTE, Observatoire de Paris. This instrument will be connected to the network of ultrastable fiber links REFIMEVE+ with the objective of contributing both to Earth sciences and to frequency metrology.**

Keywords*— *transportable clock; optical clock; ytterbium; geodesy;

I. Introduction

In the last decade, optical clocks have surpassed microwave frequency standards: overall uncertainties in the 10^{-18} or even 10^{-19} range, together with stabilities better than 10^{-16} at 1 s, were demonstrated [1-6]. This level of performance, combined to a growing technical knowledge of these instruments, opens the door to transporting them to the field to perform measurements of the gravitational potential of the Earth by remote comparisons to a network of stationary optical clocks [7, 8].

A 18 digits control over the frequency allows resolving a change of 1 cm in height, optical clocks would therefore be able to rival with the best traditional geodesy techniques, based either on spirit leveling or on satellite data. Moreover, the uncertainty depends in this case only on the performance of the clocks, and does not suffer from effects limiting these traditional methods: long distance biases, or abrupt changes of geopotential, as it happens in mountainous or coastal areas.

II. Methods/Results

In this context, SYRTE has started in 2021 the construction of a transportable ytterbium lattice clock. The project will make use of the fiber link REFIMEVE+ [9] to transport this instrument across France and to compare it to the ~12 operational stationary European optical clocks, in order to refine the realization of the geoid. REFIMEVE+ disseminates throughout the French territory a 1542 nm ultrastable reference, and measurements of the clock frequency are possible at the ~60 outputs of this fiber network against this infrared reference.

Several projects of transportable optical clocks have started in the recent years, and a few have already lead to results obtained in the field [10-12], stressing the technological and conceptual transformation necessary to prepare such a complex device against field conditions. One the main challenges to face is the loss of stability due to vibrations (ground, human activity) degrading the spectral quality of the local oscillator probing the clock transition. In order to address this issue, SYRTE is designing a clock with low dead-time in order to adjust to the decreased stability of the clock laser.

We present numerical simulations to model atom loading with the highest possible rate in a magic optical lattice. Notably, the natural divergence of the flux at the output of the atomic oven is expected to be close to 50 mrad, which results in a ~3 cm diameter after only 50 cm of propagation. We discuss the possibility to add an optical molasses stage on the strongly cycling $^1S_0$-$^1P_1$ transition at 399 nm to cool the transverse velocities, and therefore to limit the loss of atoms. We present the benefit of a 2D Magneto-Optical Trap (MOT) at 399 nm [12] to refocus the atomic flux in order to match the spatial capture range of a 3D MOT operated on the intercombination line $^1S_0$-$^3P_1$ at 556 nm. Finally, we also discuss the advantage of a deflection stage prior to lattice loading in order to filter out fast atoms and therefore to avoid hot collisions.

III. Discussion/Interpretation

With this approach, we aim at trapping >10^4 cold atoms in the lattice in 100 ms. Even with a clock laser featuring a modest flicker floor at 1×10^{-15}, this would still allow a duty cycle of 60% which corresponds to a stability of 1-2×10^{-16} at 1 s. A statistical

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resolution of 10^{-18} is then achievable after typically four hours of integration.

We also introduce the more general objectives of the project in terms of geodesy and metrology. The construction of this instrument will contribute to a refined knowledge of geoid height variations due to mass distributions. These measurements could also eventually allow the detection of early signs of rapid events such as tsunamis. In parallel, tests of fundamental physics with five atomic species (Cs, Rb, Sr, Hg and Yb) will be possible at SYRTE in the future. Finally, the operation of clocks locally based on three different optical transitions will help ascertaining frequency ratios between possible contenders to a future definition of the second based on optical transition(s) [14].

IV. Conclusions

We present in this paper the application of a quantum sensor – an optical lattice clock – to the measurement of the gravitational potential of the Earth. This quantity is not directly accessible to classical ground based sensors, which stresses the capability of atomic clocks to contribute to the field of Earth Sciences.

We describe notably the strategy we follow in order to maximize the loading rate of atoms in the magic lattice. With this approach, we aim at reaching a duty cycle larger than 50% in order to compensate for the degraded stability of the local oscillator probing the metrological transition.

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