Title: Two-species composite atomic clocks

Abstract

Optical clocks have the potential to be used as future primary standards of time and frequency and as an enabling technology for applications that require highly stable reference oscillators. Over recent years significant progress has been achieved in the stability and accuracy of ion- and atom-based optical clocks. However, no single atomic reference system is clearly in the lead to become the future primary standard. Established clock systems can be significantly improved by working in combination as a composite system allowing precise in-situ calibration and shift evaluation, with research targeting the use of multi-species atomic clocks as future SI standards. Proposals addressing this SRT should contribute towards metrology research necessary to support the use of multi-species atomic clocks as future SI standards.

Keywords

Optical clocks, trapped and cooled atoms and ions, frequency standards, frequency comparisons, SI second

Background to the Metrological Challenges

The development of highly precise optical clocks as primary standards of time and frequency, and as enablers of technological advancement has made great progress with a variety of different reference systems, neutral atoms and atomic ions. While the most advanced systems reach systematic uncertainties of 10^{-18} and below, no clearly leading atomic system has been identified.

Improved understanding of the origins and the control of systematic frequency shifts has led to proposals for novel reference systems with higher immunity to field-induced systematic shifts such as a low-energy nuclear transition in Th-229 and transitions in highly charged ions. However, these new systems pose special experimental challenges and typically do not provide closed-cycle atomic transitions for laser cooling and state detection. Therefore, techniques such as quantum-logic spectroscopy are needed to explore the possibilities of high precision laser spectroscopy on these systems. This opens novel experimental opportunities in so far inaccessible domains of atomic and nuclear physics.

While for a single ion accuracy below 10^{-18} has recently been reported, continuous operation and averaging for nearly 20 days is required to reduce the statistical uncertainty of the clock to a similar level. To significantly reduce this large frequency instability while maintaining the accuracy, correlated spectroscopy in a large ensemble clock seems to be largely beneficial as pointed out in theoretical proposals for so-called compound optical clocks. Here, initial experimental investigations with real-time data processing and work on more elaborate interrogation schemes appear to be of great value for the future primary clock systems.

Besides the combination of systems with few and many atomic absorbers, two species with different sensitivity to external perturbations in a shared spectroscopy region will enable precise in-situ calibration and shift evaluation with so far unparalleled accuracy.

To validate the results obtained with two-species compound systems, the studies should be complemented by frequency ratio measurements and direct frequency comparisons aided by fibre links.

This topic addresses the issue of a possible redefinition of the second via an optical transition frequency, an issue that has been identified as one of the “Grand challenges on fundamental metrology” within the EMRP Outline in 2008. The proposed research fulfils the recommendation of the CGPM (Resolution 8, 24th meeting 2011) which proposes that “NMIs commit resources to the development of optical frequency standards...”.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on metrology research necessary to support the use of multi-species atomic clocks as future SI standards.

The specific objectives are

1. To improve the frequency stability of optical clocks with single or few atoms/ions using information obtained in simultaneous measurements performed on ensembles of many atomic absorbers.
2. To develop and optimise the interrogation sequences, signal links and real-time data processing and cooling methods that enable composite clocks or different clock types to stabilise one common oscillator, to obtain a stability and accuracy that would not be achievable with the use of each clock system separately. This includes the application to systems that are distributed over two or more different locations.
3. To improve the frequency accuracy in single-species atomic clocks by using established reference transitions in two-species optical clocks or with atoms possessing two reference transitions using precisely measured relative sensitivities to external fields.
4. To investigate new reference transitions in two-species composite systems, to enable clock operation with so far inaccessible atomic systems such as highly charged ions. This includes the direct investigation of theoretically predicted characteristics of these transitions via the quantum-logic readout scheme.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs, research laboratories), and possible end users (space, aerospace, telecommunications, energy).

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the scientific as well as industry sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased

- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.