An optical lattice clock breadboard demonstrator for the I-SOC mission on the ISS

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The I-SOC (Space Optical Clock on ISS) mission [1] is an ESA mission whose main goal is testing the Einstein Equivalence Principle and performing relativistic geodesy from space. It will be based on a strontium lattice clock on the ISS, which will be compared with ground clocks using advanced frequency link technologies, optical and microwave. The space clock will have 1×10^{-17} fractional inaccuracy, and ground clocks intercomparisons will be possible at the 10^{-18} level.

As a breadboard demonstrator for the I-SOC optical clock, a modular and transportable Sr optical lattice clock (Fig. 1, left) has been developed [2,3]. The modular design allows to implement new laser subunits for testing purposes. The compact size of the system (970 liters) allows easy transportation by van. Low power consumption is achieved using novel solutions [4,5]. All the lasers needed for atom cooling and trapping are stabilised to a robust frequency stabilization system [6].

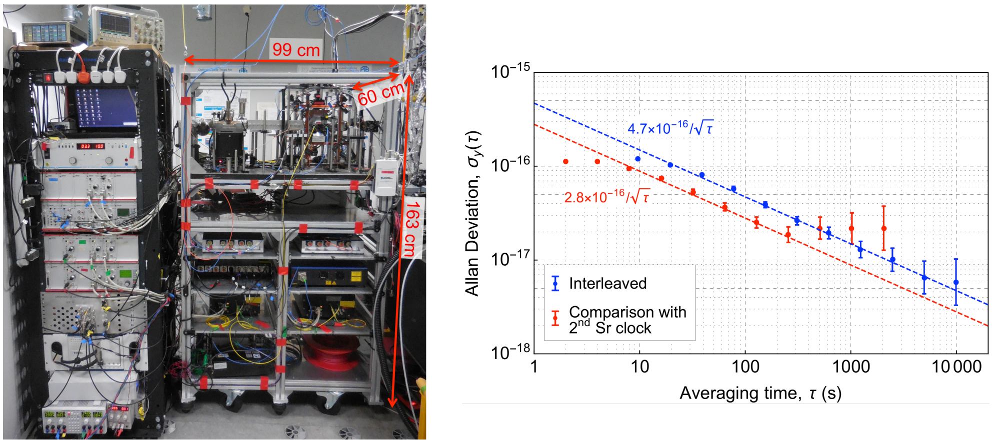

Fig. 1 Left: the Sr atomics unit including laser systems and electronics (total volume 970 l); clock laser is not shown. Right: clock instability (using a stationary reference cavity for the clock laser): interleaved instability (blue) and comparison with stationary Sr clock (red); from the latter, we can infer an instability of $2.5\times10^{-16}\,\tau^{-1/2}$ for the clock.

The atomic package was developed and operated in Birmingham and then relocated without problems by van to PTB (Braunschweig). Here the performances of the atomic package, operated with the ^{88}Sr isotope and magnetically induced spectroscopy, were evaluated using a stationary reference cavity for the 698 nm clock laser [7], and a stationary Sr clock as frequency reference [8], demonstrating an instability of $2.5\times10^{-16}\,\tau^{-1/2}$, averaging down to the 2×10^{-17} level (Fig. 1, right). The transition linewidth was 1.1 Hz.

Some systematic effects have already been determined at the $<5\times10^{-16}$ level, a full uncertainty budget at the 1×10^{-16} level is expected by mid-2017. In the near future, we will implement operation with the ^{87}Sr isotope, which is preferred as atomic frequency standard, aiming at the goal inaccuracy of 1×10^{-17}.

Finally, we will integrate a transportable clock laser cavity (fractional instability of 8×10^{-16} at 300 ms [9]) with the goal of implementing a fully transportable clock apparatus having a frequency instability $<1\times10^{-15}\,\tau^{-1/2}$.

References

[1] S. Schiller et al., "Towards Neutral-atom Space Optical Clocks (SOC2): Development of high-performance transportable and breadboard optical clocks and advanced subsystems", "Let's embrace space" Vol. II, Ch. 45, 452 (Luxembourg: Publications Office of the European Union, 2012)

[2] K. Bongs et al., "Development of a strontium optical lattice clock for the SOC mission on the ISS", C. R. Phys. **16**, 553 (2015)

[3] S. Origlia et al., "Development of a strontium optical lattice clock for the SOC mission on the ISS", Proc. SPIE **9900**, 990003 (2016); arxiv.org/abs/1603.06062

[4] I. R. Hill et al., "Zeeman slowers for strontium based on permanent magnets", J. Phys. B, At. Mol. Opt. Phys. **47**, 075006 (2014)

[5] M. Schioppo et al., "A compact and efficient strontium oven for laser-cooling experiments", Rev. Sci. Instrum. **83**, 103101 (2012)

[6] A. Nevsky et al., "Robust frequency stabilization of multiple spectroscopy lasers with large and tunable offset frequencies", Opt. Lett. **38**, 4903 (2013)

[7] S. Häfner et al., "8×10^{-17} fractional laser frequency instability with a long room-temperature cavity", Opt. Lett. **40**, 2112 (2015)

[8] A. Al-Masoudi et al., "Noise and instability of an optical lattice clock", Phys. Rev. A **92**, 063814 (2015)

[9] D. Świerad et al., "Ultra-stable clock laser system development towards space applications", Sci. Rep. **6**, 33973 (2016)