Progress in the miniature trapped ion optical clock development with 16 cc sealed trap tube

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At $3x10^{-13}/\tau^{1/2}$ and a stability floor at 10^{-15} level, JPL's Deep Space Atomic Clock (DSAC) is the state-of-the-art (SOA) microwave clock of its size, close to the size constraints in deep space applications [1]. To reach a frequency stability beyond that of DSAC in a similar size, one will have to take the new approach of the *optical clock* where the clock ticking rate is at hundreds of terahertz rather than tens of GHz. The high oscillation frequency enables the clock stability and accuracy significantly exceed what today's microwave clocks can achieve, pushing $1x10^{-17}$ accuracy and beyond [2]. The challenge is to take advantage of the optical clock performance capability in a small enough size and power to be deployed in deep space platforms. The miniature Space Optical Clock (mSOC) program focuses on studies and development efforts in reducing the size and power of an optical clock while still outperforming any microwave clocks of the similar size today by an order of magnitude in all time scales. Specifically, our objective is to develop and demonstrate an mSOC concept that will have $1x10^{-14}/\tau^{1/2}$ frequency stability with a stability floor $<1x10^{-16}$.

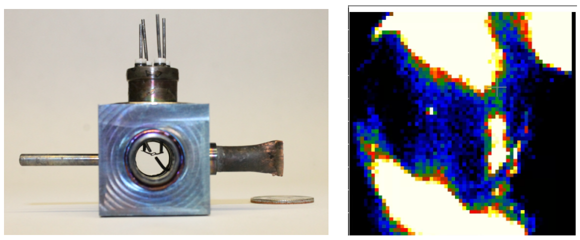

Fig.1. Sealed single ion trap tube of mSOC (left) and a camera image of a single trapped Yb+ (right).

From a system engineering perspective, we find that the approach of singly trapped ions will have the most creditable path to minimizing the overall size and power goals. The core of mSOC is an ultra-high vacuum tube that houses nearly perturbation-free laser-cooled and trapped atomic (ion) reference. Currently, we use $^{171}Yb^+$, but other ion species are possible. In this paper, we will describe the mSOC concept, discuss the experimental setup, and present results. We will show that we have demonstrated a 16-cc single ion trap tube that is completed sealed off and standalone without any active pump attached (Fig.1). The realization of trapping single ions in a small, sealed package will lead to small sizes and low powers in lasers and optics, and more importantly magnetic and thermal management that will dominate the overall system size and power.

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References

[1] Burt, E.A., Prestage, J.D., Tjoelker, R.L. *et al.* Demonstration of a trapped-ion atomic clock in space. *Nature* **595**, 43–47 (2021). https://doi.org/10.1038/s41586-021-03571-7.

[2] Dörscher, S., Huntemann, N., Schwarz, R., Lange, R., Benkler, E., Lipphardt, B., Sterr, U., Peik, E., & Lisdat, C. (2020). Optical frequency ratio of a 171Yb+ single-ion clock and a 87Sr lattice clock. *Metrologia, 58.*