National Aeronautics and Space Administration

Miniature Space Optical Clock

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Strategic Focus Area: Space Clocks - Strategic Initiative Leader: Todd A Ely

OBJECTIVES

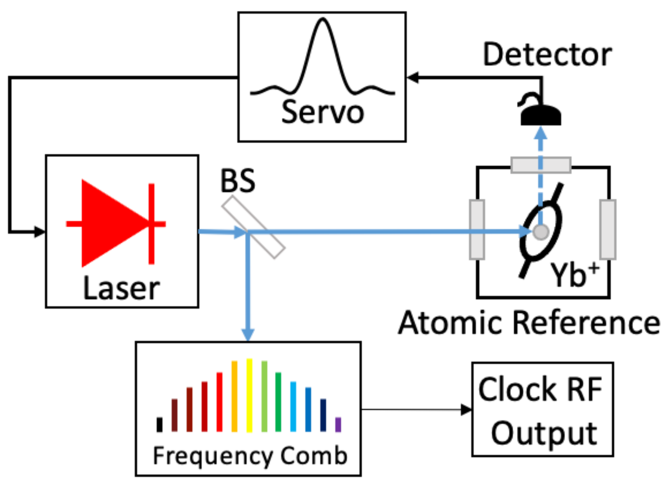
The overall objective of the initiative effort is to develop and demonstrate the miniature optical clock concept that will have both short-term and long-term stability 10x better than the state-of-the-art microwave clocks such as Deep Space Atomic Clock (DSAC). With the single trapped ion as the atomic reference approach, it is possible to make the whole clock system small enough to deploy in Deep Space.

BACKGROUND

Currently, JPL's DSAC is the state-of-the-art microwave clock of its size. To reach beyond the DSAC capability, one will have to take the new approach of the *optical clock* where the clock ticking rate is at hundreds of THz rather than tens of GHz. The high oscillation frequency enables the clock stability and accuracy performance beyond today's microwave clocks. This effort aims at developing key components to advance the state-of-the-art of Space Clocks - ultimately leading to a complete optical space clock system. The targeted mSOC clock performance (stability and accuracy) and SWAP-C (size, weight, power, and cost) have been chosen to maximize the utility of this instrument for future JPL/NASA missions.

APPROACH AND RESULTS

The fundamental structure of an atomic clock is straightforward – an atomic reference is used to steer and stabilize an oscillator that does the clock ticking. The clock performance critically depends on the atomic reference. This approach leverages JPL's unique capability of ion trapping in a small sealed vacuum package to develop an atomic reference with a single trapped ytterbium ion. Overall, we have fabricated the trap tube and established the necessary experimental clock tabletop subsystems to characterize and validate the atomic reference performances. The trap tube is a completely sealed vacuum system without an active pump. We have demonstrated the ability to trap and confine ytterbium ions in the vacuum tube with a long lifetime and confirmed the single ion state, together with other experimental capabilities, to make it possible. A tabletop clock laser was completed, and its performance was assessed.



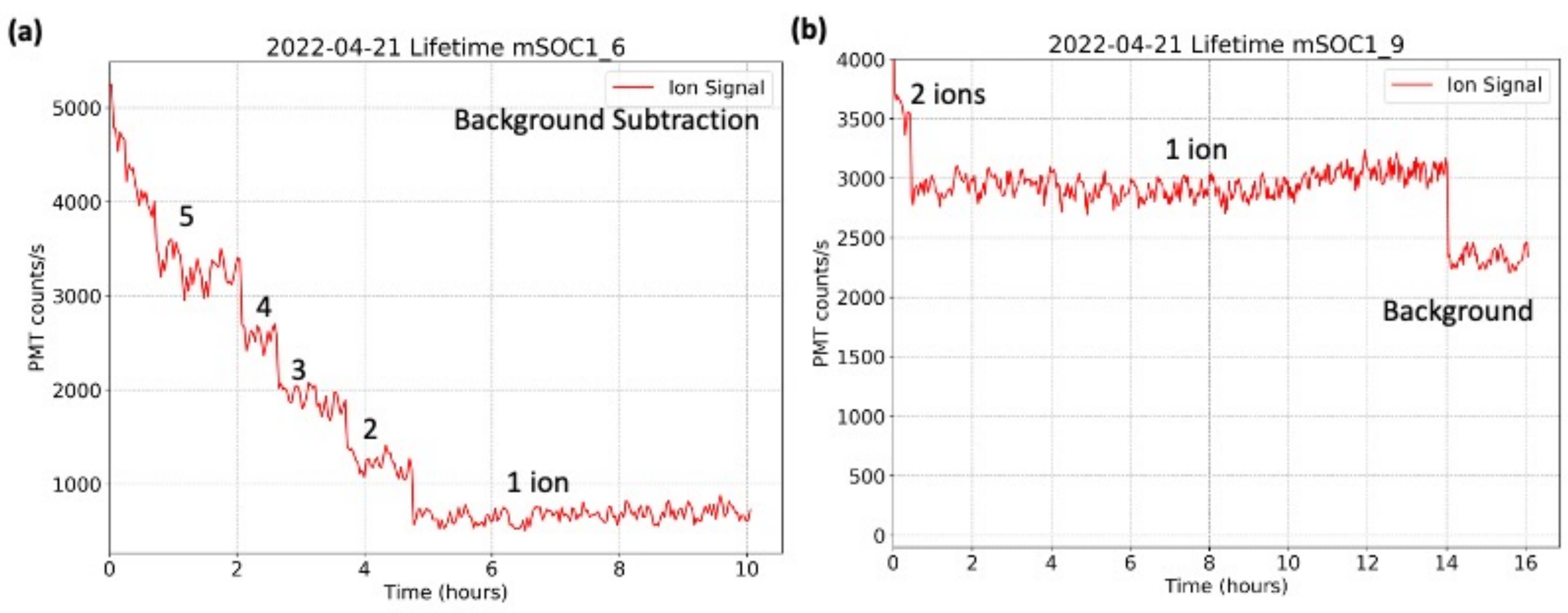


Figure 1. (a), Discrete signal steps of a few trapped ions. (b), Single ion lifetime measurement.

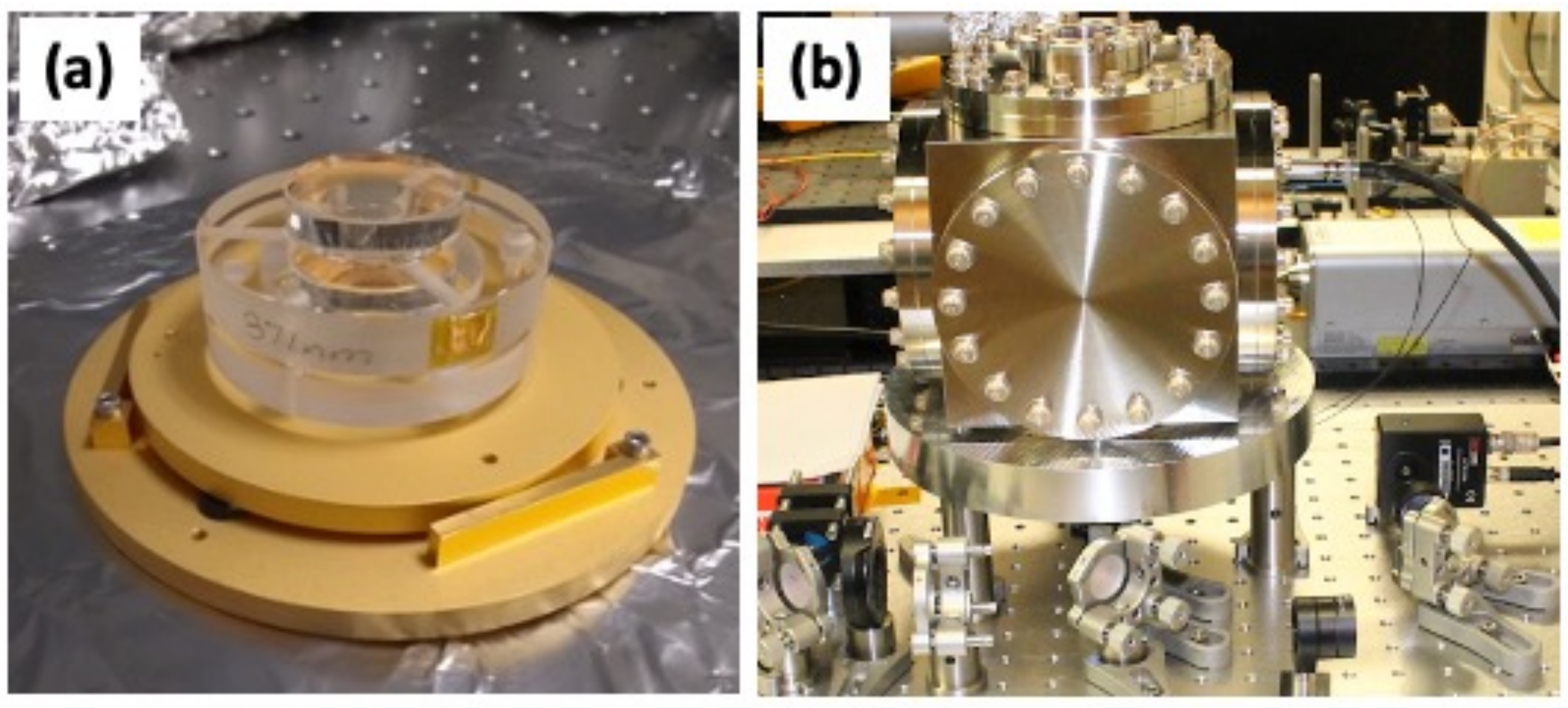


Figure 2. (a), Cavity installed on the cavity support in the two-layer thermal shield. (b), The cavity was housed inside a vacuum chamber.

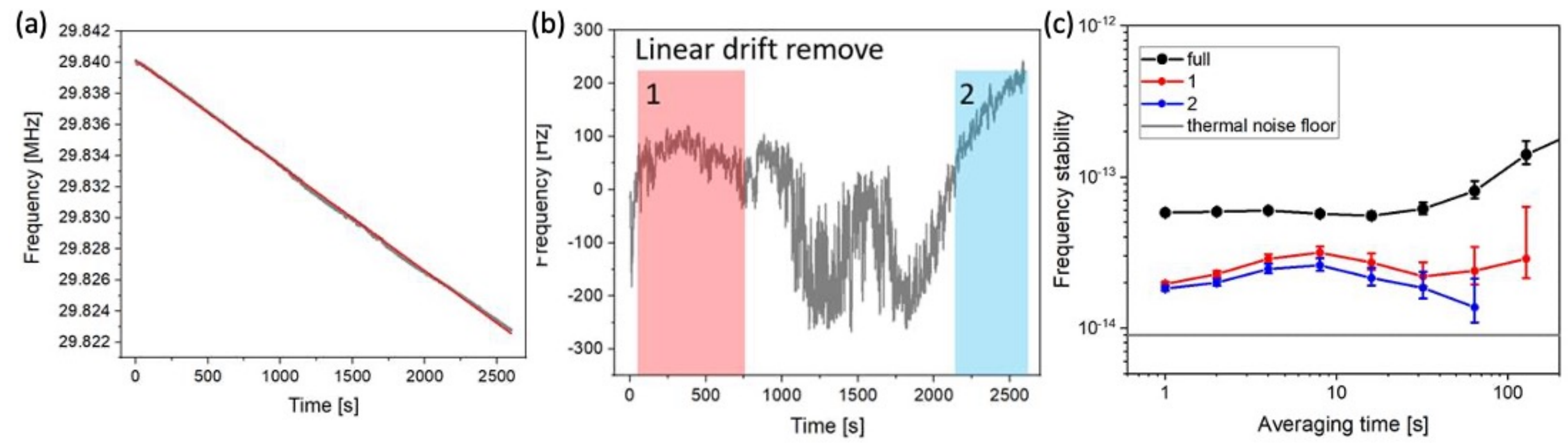


Figure 3. (a), The beat note between the cavity stabilized laser at 872 nm, and adjacent comb line (black) and the linear drift is 6.5 Hz/s (red). (b), The beat note with linear drift remove. Two sections, highlighted as 1 and 2, in the data record show less noise from the comb. (c), The frequency stability for the whole data record is shown in black, section 1 in red, and section 2 in blue, respectively. In these two selected sections, the frequency stability is close to the cavity thermal noise (grey) 9E-15

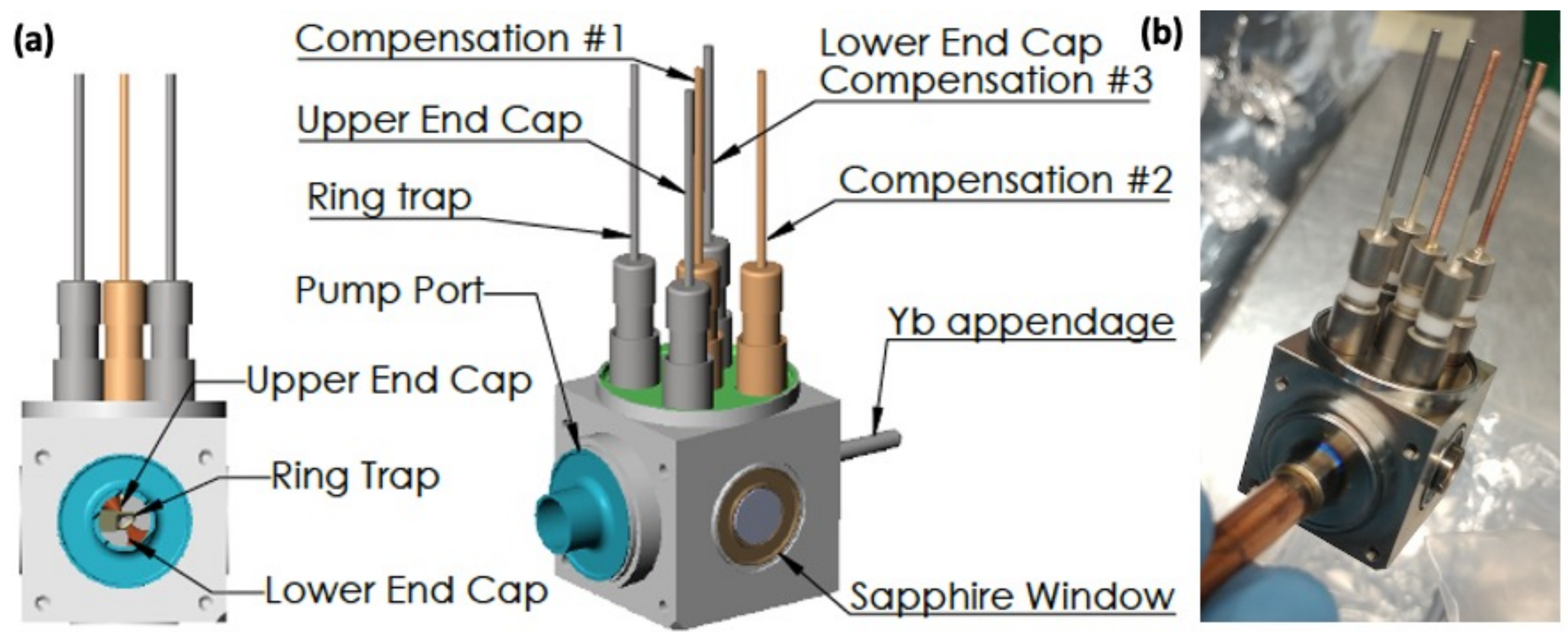


Figure 4. (a) Computer-aided design and (b) actual photograph of a new trap tube with compensation electrodes.

SIGNIFICANCE/BENEFITS TO JPL AND NASA

The new capability of the miniature space optical clock will make a significant impact on NASA's Deep Space Network antenna resource utilization efficiencies, system autonomy and robustness, and space Position, Navigation, and Timing capabilities in general. It could enable new scientific measurements as well as detections of dark matter ultra-light fields and improve radio tracking planetary gravity and atmosphere occultation measurements.

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Publications:

W. Zhang, T. Le, T. Hoang, M. Langlois, N. Yu, and A. Matsko, "Compact Fabry-Perot cavity for Yb ion clock," submitted to Conference Photonics West, LA203, Laser Resonators, Microresonators, and Beam Control XXV, 2023.

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