# The Deep Space Atomic Clock: Demonstration of a Trapped Ion Atomic Clock in Space

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The methods of trapping and cooling of atoms and ions have been transformative for atomic clocks due to the reduction and in some cases elimination of major systematic frequency shifts [1], [2], [3]. Trapped atom/ion optical clocks have achieved orders of magnitude improvements in performance over their predecessors and have become a key component in national metrology laboratory research programs [4], [5]. Continuously operating atomic clocks based on trapped ions have existed for decades but have until now been restricted to terrestrial applications [6]. Here we report on NASA's Deep Space Atomic Clock (DSAC), which was launched in 2019 and became the first trapped ion atomic clock to operate in space [7]. The DSAC design did not include cryogenics, a sensitive microwave cavity, nor lasers. Instead, it operated at near room temperature, used simple travelling wave microwave components, and used a plasma discharge deep UV light source. The high maturity and robust operability of each of these enabled launch into and operation in space. On the ground, DSAC demonstrated a short-term fractional frequency stability of $1.5x10^{-13}/t^{1/2}$ [8]. In space it operated for 2 years where it achieved a fractional frequency stability of $1.5x10^{-13}$ at one second, a long-term stability of $3x10^{-15}$ for averaging times greater than a day, a time deviation of only 4 ns at 23 days (no drift removal), and an estimated drift of $3.0(0.7)x10^{-16}$ per day. Among the most stable space clocks currently in use, each of these established a new space clock performance standard by at least an order of magnitude [9], [10], [11]. The DSAC clock was also amenable to the space environment, due to low sensitivities to variations in radiation, temperature, and magnetic fields. It is expected that this level of space clock performance will enable one-way navigation whereby signal delay times are measured in-situ making near-real-time deep space probe navigation possible [12]. In this paper we will describe the DSAC performance in space along with its environmental sensitivities, the primary applications of this technology, and future directions.

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