# Developing Yb and Sr optical lattice clocks in the same laboratory

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The precise measurement of time and frequency is of great interest for a wide range of applications, including fundamental science and metrology. Optical frequency standards have been extensively studied, and great strives have been made in improving their frequency stability and reducing uncertainty over the past few decades. While the ion clock uses a single quantum absorber for an atomic reference, an optical lattice clock uses thousands of atoms[1]. Thanks to the small quantum projection noise of an optical lattice clock, its stability can surpass that of an ion clock. Very recently a stability of $1.6\times10^{-18}$ has been achieved with an Yb optical lattice clock[2] and a reproducibility of $6\times10^{-18}$ has been demonstrated with a Sr optical lattice clock[3].

We have developed an Yb optical lattice clock operated with non spin-polarized $^{171}$Yb atoms[4]. The atoms were loaded into a horizontally oriented one-dimensional optical lattice. The clock transition is observed and the absolute frequency is determined as 518 295 836 590 863.1 (2.0) Hz. The uncertainty evaluation shows that the reproducibility of the Yb lattice clock is $4.1\times10^{-16}$. We have also developed a Sr optical lattice clock operated with spin-polarized $^{87}$Sr atoms[5]. The atoms were loaded into a vertically one-dimensional optical lattice. The clock transition is observed and the absolute frequency is determined as 429 228 004 229 872.0 (1.6) Hz. The uncertainty evaluation shows that the reproducibility of the Sr lattice clock is $3.8\times10^{-16}$.

The frequency ratio of $^{171}$Yb and $^{87}$Sr is measured by an optical-optical direct frequency link between the two optical lattice clocks using a narrow-linewidth fiber comb. We determined the frequency ratio with a fractional uncertainty smaller than that obtained from absolute frequency measurements using the combination of a H-maser and the International Atomic Time (TAI) link. Since the two lattice clocks are sitting in the same lab, the height difference between the two clocks is measured with an uncertainty of 5 mm, which has a negligible contribution to the uncertainty due to the gravitational shift. The measured ratio agrees well with that derived from the absolute frequency measurement results obtained at NIST and JILA, Boulder, CO using their Cs-fountain clock[6]. Our measurement enables the first international comparison of the frequency ratios of optical clocks, and we obtained a good agreement between the two measured ratios with an uncertainty smaller than the TAI link.

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