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Frequency ratios of optical lattice clocks at the 17th decimal place

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Optical lattice clocks benefit from a low quantum-projection noise by simultaneously interrogating a large number of atoms, which are trapped in an optical lattice tuned to the "magic wavelength"to largely cancel out light shift perturbation in the clock transition. About a thousand atoms enable the clocks to achieve 10^{-18} instability in a few hours of operation, allowing intensive investigation and control of systematic uncertainties. It is now the uncertainty of the SI second ($\sim 10^{-16}$) itself that restricts the measurement of the absolute frequencies of such optical clocks. Direct comparisons of optical clocks are, therefore, the only way to investigate and utilize their superb performance beyond the SI second.

In this presentation, we report on frequency comparisons of optical lattice clocks with neutral strontium (^{87}Sr), ytterbium (^{171}Yb) and mercury (^{199}Hg) atoms. By referencing cryogenic Sr clocks [1], we determine frequency ratios, $\nu_{\mathrm{Yb}}/\nu_{\mathrm{Sr}}$ [2] and $\nu_{\mathrm{Hg}}/\nu_{\mathrm{Sr}}$ [3], of a cryogenic Yb clock and a Hg clock with uncertainty at the mid 10^{-17}. Such ratios provide an access to search for temporal variation of the fundamental constants. We also present remote comparisons between cryogenic Sr clocks located at RIKEN and the University of Tokyo over a 30-km-long phase-stabilized fiber link. The gravitational red shift $\Delta\nu/\nu_0 \approx 1.1\times10^{-18}\ \Delta h\ \mathrm{cm}^{-1}$ reads out the height difference of Δh˜15 m between the two clocks with uncertainty of 5 cm, which demonstrates a step towards relativistic geodesy. We also mention our ongoing experiments that reduce clock uncertainty to 10^{-19} by applying "operational magic frequency,"[4], where light shifts due to dipole, multipolar, and hyper-polarizability effects effectively cancel out for a certain range of optical lattice intensity.

[1] I. Ushijima, et al., Nature Photon. 9, 185 (2015).
[2] N. Nemitz, et al., Nature Photon. 10, 258 (2016).
[3] K. Yamanaka, et al., Phys. Rev. Lett. 114, 230801 (2015).
[4] H. Katori, et al., Phys. Rev. A 91, 052503 (2015).

Summary

Presenter: Prof. KATORI, Hidetoshi (University of Tokyo, Japan)

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