New super-accurate optical atomic clocks pass critical test

April 11 2019

Credit: CC0 Public Domain

Researchers have measured an optical clock's ticking with record-breaking accuracy while also showing the clock can be operated with unprecedented consistency. These achievements represent a significant step toward demonstrating that the new generation of optical atomic clocks are accurate and robust enough to be used to redefine the official length of a second, which is currently based on microwave atomic clocks.

"A more accurate definition of a second and a better time-keeping infrastructure would support continuing advances in the timing systems used in a wide range of applications, including communication and navigation systems," said Andrew Ludlow, one of the research team leaders from the National Institute of Standards and Technology (NIST), USA. "It would also provide more precise measurements for exploring physical phenomena that aren't yet fully understood."

The new research is reported in *Optica*.

"Optical clocks are likely capable of much higher accuracy, probably 10 to 100 times better than what we measured in this work," said Ludlow. "To prove the true accuracy of these clocks without being limited by today's definition of a second will require high-quality comparisons directly between various types of optical clocks."

Why use an optical clock?

Clocks work by counting a reoccurring event with a known frequency, such as the swinging of a pendulum. For traditional atomic clocks the recurrent event is the natural oscillation of the cesium atom, which has a frequency in the microwave region of the electromagnetic spectrum. Since 1967, the International System of Units (SI) has defined a second as the time that elapses during 9,192,631,770 cycles of the microwave signal produced by these oscillations.

Optical atomic clocks use atoms such as ytterbium and strontium that oscillate about 100,000 times higher than microwave frequencies, in the optical, or visible, part of the electromagnetic spectrum. These higher frequencies allow optical clocks to tick faster than microwave atomic clocks, making them more accurate and stable over time.

"The higher frequencies measured by optical clocks generally make it easier to control environmental influences on the atoms," said Tara Fortier, a member of the research team. "This advantage could eventually enable the development of compact optical clock systems that maintain relatively high performance in a wide range of application environments."

Achieving record accuracy

To show that time kept with an optical clock is compatible with today's standard cesium atomic clocks, the researchers converted the frequency of an ytterbium optical atomic clock at NIST to the microwave region and compared it with a collection of measurements from cesium atomic clocks located across the globe.

They achieved frequency measurements of the ytterbium optical clock with an uncertainty of 2.1 X 10-16. This corresponds to losing only about 100 seconds over the age of the universe (14 billion years) and sets a new accuracy record for cesium-referenced measurements of an optical clock.

Although optical clocks are very accurate, they do tend to experience significant downtimes because of their technical complexity and prototype design. The researchers at NIST used a group of eight hydrogen masers to keep the time when the optical clock wasn't operational. Masers, which are like lasers that operate in the microwave spectral range, can reliably keep time but have limited accuracy.

"The stability of the masers—one of the best local time scales in the world—is one reason why we were able to perform such an accurate comparison to cesium," said Tom Parker, a member of the research team. They further reduced the uncertainty by making 79 measurements over 8 months. This is the first time that optical clock measurements have been reported over such a long time period.

To better understand the limits of optical clocks, the researchers plan to compare the ytterbium optical clock used in this study with other types of optical clocks under development at NIST. Eventually, the NIST clocks could be compared with optical clocks in other countries to determine which types of clocks would be best for redefining the SI second.

The researchers point out that redefining the length of a second is still some years away. Even if it does change, applying the new standard would require technology that better connects and transmits signals from optical clocks around the world in a way that maintains stability and the accuracy of the time.

More information: W. F. McGrew, X. Zhang, H. Leopardi, R.J. Fasano, D. Nicolodi, K. Beloy, J. Yao, J. A. Sherman, S. A. Schäffer, J. Savory, R.C. Brown, S. Römisch, C.W. Oates, T.E. Parker, T.M. Fortier, A.D. Ludlow, "Towards the optical second: Verifying optical clocks at the SI limit," *Optica*, 6, 4, 448-454 (2019). DOI: 10.1364/OPTICA.6.000448

Provided by Optical Society of America