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Toward a Reliable Optical Timescale

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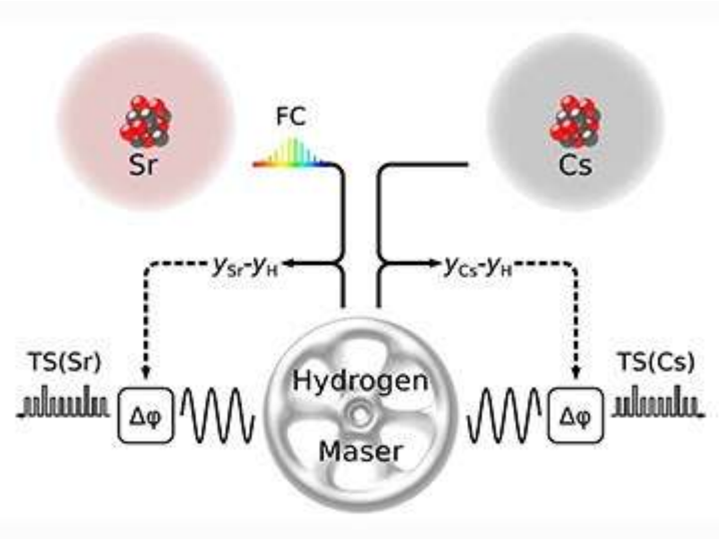
For a number of years, optical lattice clocks have shown mind-bending levels of accuracy and stability, surpassing those of even the best atomic clocks (see "Optical Lattice Clocks," OPN, January 2015). But putting that timekeeping muscle to work as a global time standard has faced a stumbling block: the comparatively lower reliability of optical clocks for continuous long-term operation.

Now, a team of German scientists has demonstrated a way to bridge that reliability gap (Optica, doi: 10.1364/optica.3.000563). It's a finding that opens a practical path to an optical standard of precision for the pulse that underlies GPS location measurements, split-second financial transactions, and even the definition of the SI second itself.



The PTB team demonstrated that a reliable strontium-based optical lattice clock (left) was feasible by tying the strontium clock to a continually running hydrogen maser "flywheel oscillator," and using the maser signal to bridge downtimes in the strontium clock. Such a scheme is already used for local timescales based on conventional cesium atomic clocks (right), which have less downtime, but also more than an order of magnitude less accuracy, than optical clocks. [Image: Grebing et al., Optica, doi: 10.1364/optica.3.000563].

Beyond nanosecond errors?

The primary global timekeeping standard is Universal Coordinated Time (UTC), a worldwide agreement that tracks arcana such as time-zone offsets, the occasional addition of "leap seconds" to the international calendar, and just what the definition of a standard "second" actually is. The UTC framework relies on a weighted average of satellite-linked information from a byzantine system of some 500 atomic clocks, which provide a precise time pulse based on the microwave-frequency oscillations of cesium atoms. (Indeed, since 1967, the standard second has been defined as the time that elapses during 9,192,631,770 such oscillations.) Individual time laboratories create their own local timescales through periodic comparisons and synchronizations against these primary cesium clocks.

The precision of atomic clocks has been sufficient to allow advances such as the worldwide GPS now taken for granted. But even these precise clocks can accumulate errors of 1 ns per month. Such an error may seem trivial—but it's becoming increasingly relevant as fundamental physics probes events in the attosecond realm, and as an increasingly interconnected and competitive commercial world pushes the frontiers of data volumes and time precision in search of an edge. Financial networks, for example, could use a more precise timescale to allow for more precise timestamps on individual transactions.

Optical clocks: nonpareil accuracy, spotty reliability

Optical lattice clocks—which use lasers tuned to specific electronic transitions of heavy atoms such as strontium to read a signal from ultracold atoms confined in an optical trap—offer accuracy and stability levels an order of magnitude or more greater than cesium clocks. That's because the frequency "tick" that underlies them lies in the optical rather than the microwave band.

These accuracy advantages make optical lattice clocks a natural successor to conventional cesium atomic clocks in the quest for ever-more-precise timekeeping. But there's a catch: optical lattice clocks tend to show substantially more downtime, and less long-term reliability, than the cesium variety, which has made their adoption as a continuous timescale difficult to envision.

Finding a reliability bridge

To lay a path toward reliable use of optical clocks as a global standard, Christian Grebing and colleagues at Germany's national metrology institute, the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, took a page from the experience of the UTC system. In the current system, local time laboratories often maintain their own working timescales by comparing the global UTC cesium clock ensemble with a continually running "flywheel oscillator," such as a hydrogen maser. The maser's output frequency, which is in the same frequency zone as the cesium atom's oscillations, is "steered" on a monthly basis to stay synchronized with the UTC clock ensemble. The system allows a time reading of reasonable reliability on a local basis whenever it's needed.

The PTB group decided to see if adapting that system to an optical-clock framework could compensate for the more frequent downtimes experienced by optical lattice clocks. During two 25-day campaigns in October 2014 and June 2015, the scientists tied a commercially available hydrogen flywheel maser to PTB's strontium optical clock, using a femtosecond frequency comb to down-convert the clock light to the microwave regime. A steering algorithm compares the average maser frequency, on an hourly basis, with the frequency information available from the strontium optical clock. The fractional frequency difference is used to calibrate the more reliable, but less accurate, flywheel maser signal during the strontium clock's downtime periods.

Fivefold error reduction

The result is the potential for a continuous timescale, as with the current UTC system—but at accuracies closer to those of the strontium clock. The PTB team's study found that, even with the optical clock running less than 50 percent of the time, with downtimes ranging from minutes to several days, the maser/optical-clock combination accumulated time errors of less than 200 picoseconds over 25 days, a nearly fivefold improvement relative to the best cesium atomic clocks. And, the authors suggest, improvements to the system—including the use of other types of flywheel oscillators, averaging of multiple optical-clock signals to reduce aggregate downtimes, and better optimization of optical clocks for reliability—could push those accumulated errors down still further, to the area of less than 15 ps over 30 days.

An optical-clock standard for the SI second, notes lead author Grebing, may still be a decade or so away, as the ultimate accuracy of optical clocks is still being probed and as several types of clocks would likely vie for the ultimate standards crown. But, he believes, the PTB team's demonstration represents "a first step towards a global improvement of timekeeping."