JILA team demonstrates model system for distribution of more accurate time signals

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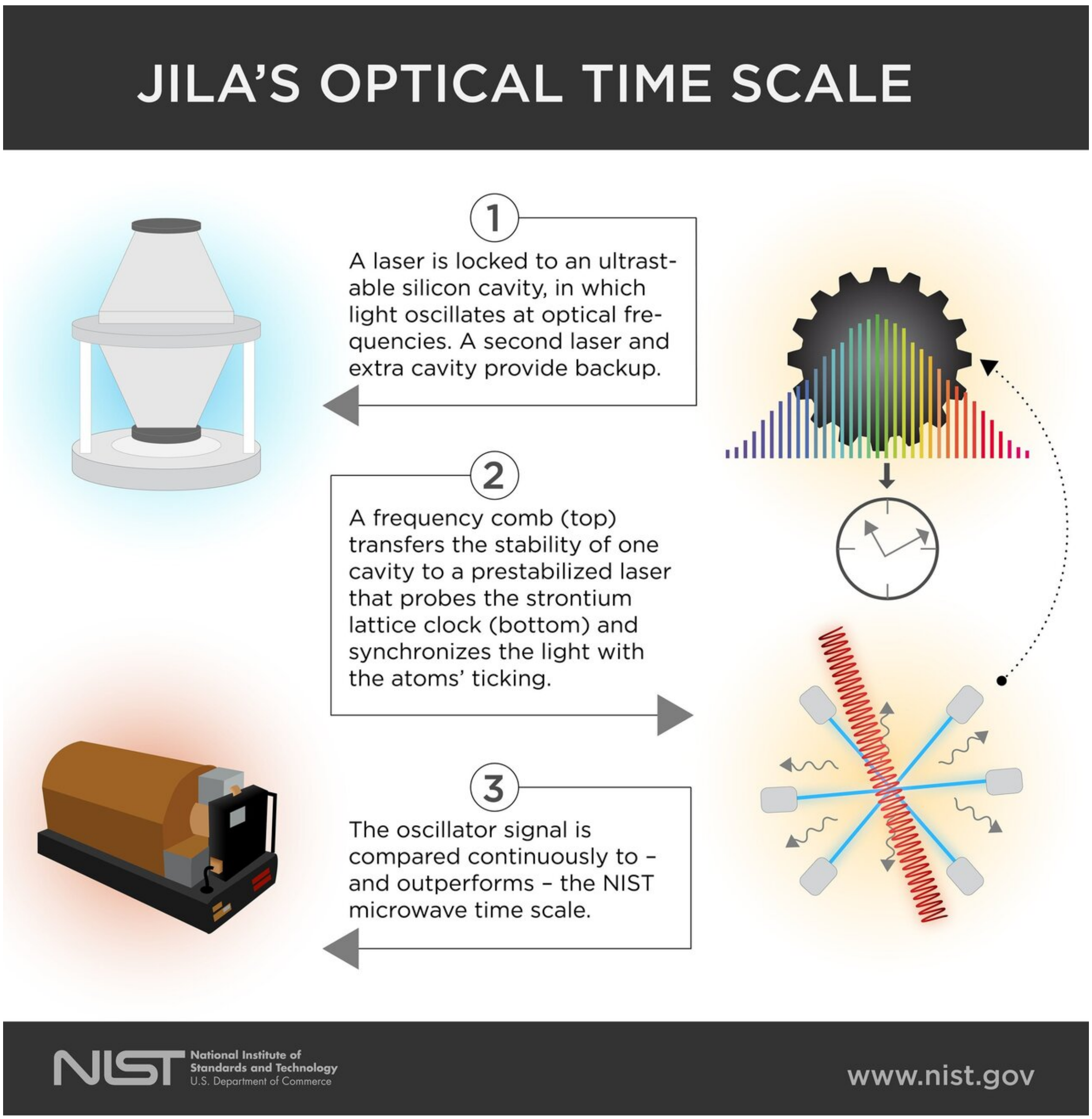

JILA's 'time scale' produces a highly accurate timekeeping signal at optical frequencies for possible future distribution. Credit: N. Hanacek/NIST

JILA physicists and collaborators have demonstrated the first next-generation "time scale"—a system that incorporates data from multiple atomic clocks to produce a single highly accurate timekeeping signal for distribution. The JILA time scale outperforms the best existing hubs for disseminating official time worldwide and offers the possibility of providing more accurate time to millions of customers such as financial markets and computer and phone networks.

The novel time scale architecture combines a super-reliable, advanced atomic clock with an ultrastable device for storing time signals and is a "blueprint for the upgrade of time scales worldwide," as described in the journal *Physical Review Letters*.

JILA is jointly operated by the National Institute of Standards and Technology (NIST) and the University of Colorado Boulder.

"I think this new time scale demonstration will be very important for the redefinition of time in the future," said Jun Ye, NIST/JILA fellow and project leader.

The recent redefinition of the International System of Units (SI) did not update the way time is measured. The standard unit of time, the second, has been based on properties of the cesium atom since 1967. In the coming years, the international scientific community is expected to redefine the second, selecting a new atom as the basis for standard atomic clocks and official timekeeping.

To prepare for this change, researchers need to upgrade systems for distributing time.

NIST operates the nation's civilian time scales, arrays of hydrogen masers—microwave versions of lasers—that provide reliable oscillating signals to maintain stable "ticking" for the official U.S. civilian time of day, which is linked to international time (coordinated universal time or UTC). Two atomic clocks based on the cesium standard, called NIST-F1 and NIST-F2, are used to calibrate and ensure the accuracy of the time scales.

Like next-generation atomic clocks, JILA's experimental time scale operates entirely at optical frequencies, which are much higher than the microwave frequencies of cesium time standards. Optical frequencies divide time into smaller units and thus can offer greater accuracy.

Efforts to incorporate the latest optical atomic clocks into older microwave time scales have run into limits on long-term stability, due to the inherent properties of masers and the fluctuations associated with linking them to experimental clocks that operate intermittently.

The JILA team solved these problems by optimizing a more stable type of oscillator and tightly controlling operating conditions such as temperature so their highly stable and precise strontium lattice clock can be operated regularly on demand.

The oscillator is formed by a laser beam aimed into a hollow cavity made of a single crystal of silicon, inside of which laser light of a specific color, or frequency, bounces back and forth regularly for a long time, like a metronome. These devices have been around for years, but a long-term JILA collaboration with Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute, came up with a new way of building them, greatly improving the stability of the light. Recently, the JILA team further boosted the long-term stability of their cavity, which is 21 centimeters long and operates at cryogenic temperatures of 124 K (minus 149.15 C), by using superpolished optics and improved heat control, among other tweaks.

In the JILA time scale, an optical frequency comb (a ruler for light) transfers the stable optical signal from this cavity to another, very stable laser that is shined on the clock's atoms and synchronizes the light's frequency with their ticking. Two additional lasers are stabilized to independent cavities. The multiple lasers and cavities provide redundancy in case anything malfunctions.

The stability of the oscillator was compared continuously to that of the NIST microwave time scale by a preexisting underground fiber-optic link between JILA, on the university's campus, and NIST, a mile or so away. Over a month of measurements, the frequency stability of the optical oscillator consistently surpassed that of the masers in the microwave time scale.

The experimental results show that the JILA time scale architecture outperforms microwave time scales, even when the masers are calibrated by next-generation atomic clocks. The team's analysis indicates that by running the JILA optical clock 50% of the time, the all-optical time scale could reach a stability level about 10 times better than the standard microwave time scale, or 1×10^{-17}, after a few months of averaging.

A further practical advantage is that the oscillator frequency can be predicted using conventional microwave analysis techniques, enabling the team to estimate a timing error of only 48 ± 94 picoseconds (trillionths of a second) after 34 days of operation.

Additional technical upgrades are planned, including automation that should allow the clock to be operated more than 50% of the time.

Researchers also plan to incorporate the optical time scale signal into the NIST time scale using the underground fiber network.

More information: William R. Milner et al. Demonstration of a Timescale Based on a Stable Optical Carrier, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.173201

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