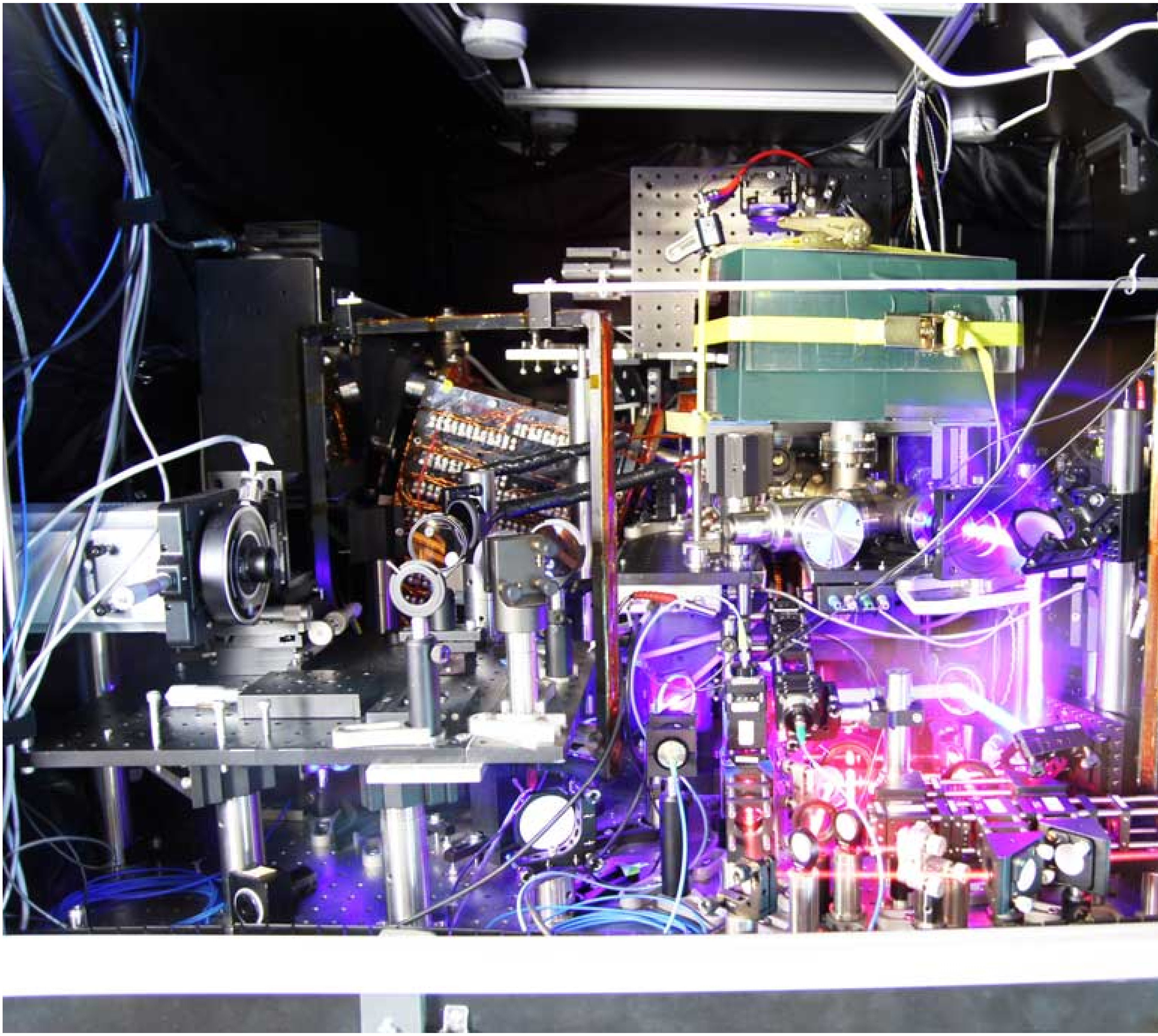
A millimeter might not seem like much. But even a distance that small can alter the flow of time.

According to Einstein's theory of gravity, general relativity, clocks tick faster the farther they are from Earth or another massive object (*SN: 10/4/15*). Theoretically, that should hold true even for very small differences in the heights of clocks. Now an incredibly sensitive atomic clock has spotted that speedup across a millimeter-sized sample of atoms, revealing the effect over a smaller height difference than ever before. Time moved slightly faster at the top of that sample than at the bottom, researchers report September 24 at arXiv.org.

"This is fantastic," says theoretical physicist Marianna Safronova of the University of Delaware in Newark, who was not involved with the research. "I thought it would take much longer to get to this point." The extreme precision of the atomic clock's measurement suggests the potential to use the sensitive timepieces to test other fundamental concepts in physics.

An inherent property of atoms allows scientists to use them as timepieces. Atoms exist at different energy levels, and a specific frequency of light makes them jump from one level to another. That frequency — the rate of wiggling of the light's waves — serves the same purpose as a clock's regularly ticking second hand. For atoms farther from the ground, time runs faster, so a greater frequency of light will be needed to make the energy jump. Previously, scientists have measured this frequency shift, known as gravitational redshift, across a height difference of 33 centimeters (*SN: 9/23/10*).

In the new study, physicist Jun Ye of JILA in Boulder, Colo., and colleagues used a clock made up of roughly 100,000 ultracold strontium atoms. Those atoms were arranged in a lattice, meaning that the atoms sat at a series of different heights as if standing on the rungs of a ladder. Mapping out how the frequency changed over those heights revealed a shift. After correcting for non-gravitational effects that could shift the frequency, the clock's frequency changed by about a hundredth of a quadrillionth of a percent over a millimeter, just the amount expected according to general relativity.

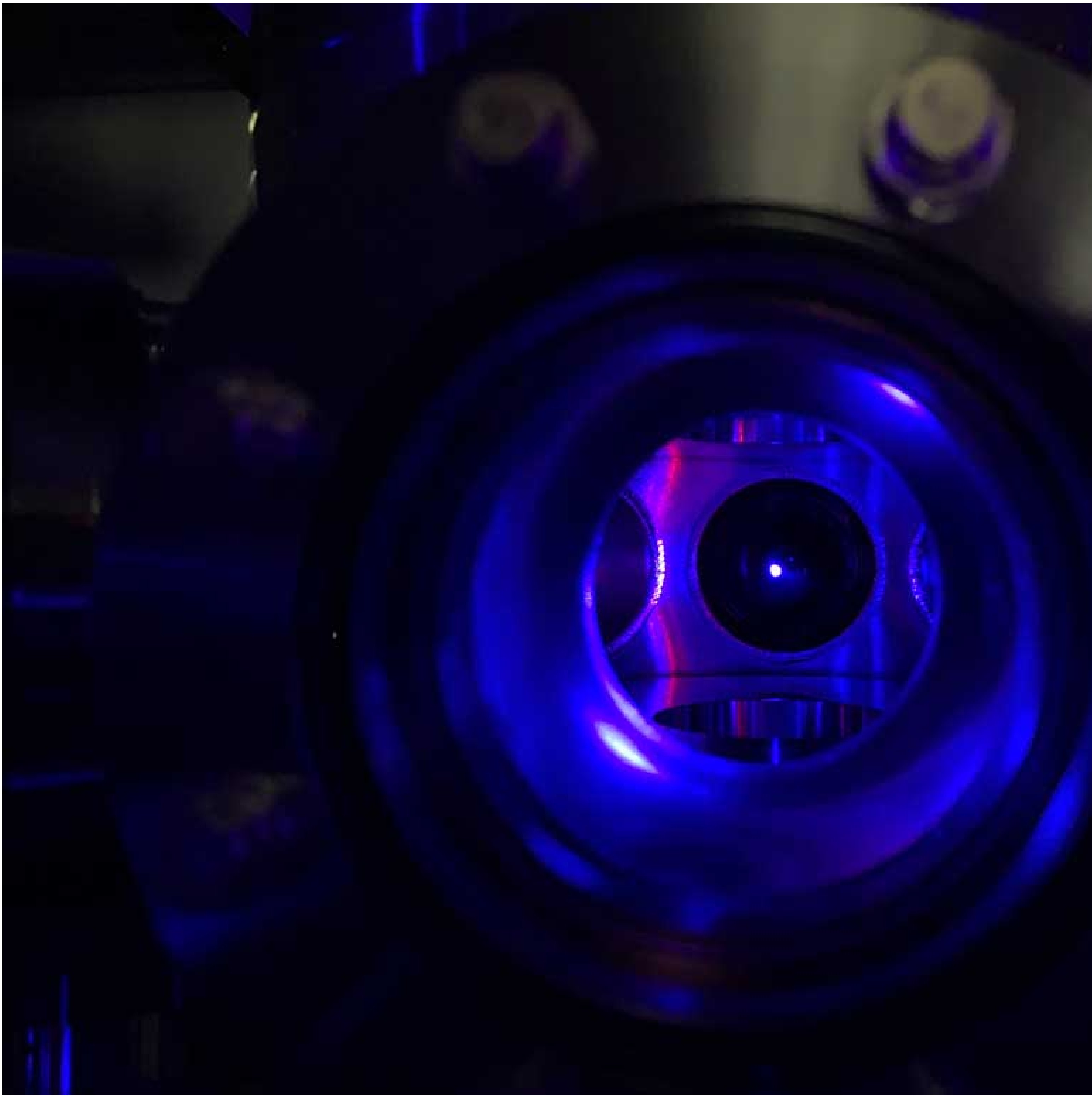


Atomic clocks (one shown in a composite image) keep time by measuring the frequency of light that initiates a jump between energy levels in atoms. This atomic clock, located at JILA, is similar to the one used in the new research by Jun Ye and colleagues, and uses laser light to hold strontium atoms in a lattice.Ye group and Baxley/JILA

What’s more, after taking data for about 90 hours, comparing the ticking of upper and lower sections of the clock, the scientists determined their technique could measure the relative ticking rates to a precision of 0.76 millionths of a trillionth of a percent. That makes it a record for the most precise frequency comparison ever performed.

In a related study, also submitted September 24 to arXiv.org, another team of researchers loaded strontium atoms into specific portions of a lattice to create six clocks in one. “It’s very exciting what they did, as well,” Safronova says.

Shimon Kolkowitz of the University of Wisconsin–Madison and colleagues measured the relative ticking rates of two of the clocks, separated by about six millimeters, to a precision of 8.9 millionths of a trillionth of a percent, which itself would have been a new record had it not been beat by Ye’s group. With that sensitivity, scientists could detect a difference between two clocks ticking at a rate so slightly different that they’d disagree by just one second after about 300 billion years. Ye’s clock could detect an even smaller discrepancy between the two halves of the clock of one second amassed over roughly 4 trillion years. Although Kolkowitz’s team didn’t yet measure gravitational redshift, the setup could be used for that in the future.



A cloud of strontium atoms (glowing blue dot at center) is trapped inside a vacuum chamber that contains Shimon Kolkowitz and colleagues' atomic clock. In the experiment, the atoms were shuttled into different parts of a lattice to make multiple atomic clocks in one.S. Kolkowitz

Authors of both studies declined to comment, as the papers have not yet been through the peer-review process.

The measurements' precision hints at future possibilities, says theoretical physicist Victor Flambaum of the University of New South Wales in Sydney. For example, "atomic clocks are now so precise that they may be used to search for dark matter," he says. This stealthy, unidentified substance lurks invisibly in the cosmos; certain hypothesized types of dark matter could alter clocks' tick-tocks. Scientists could also compare atomic clocks made of different isotopes — atoms with varied numbers of neutrons in their nuclei — which might hint at undiscovered new particles. And atomic clocks can study whether fundamental constants of nature might vary (*SN: 11/2/16*).

The ability to precisely compare different clocks is also important for a major goal of timekeeping: updating the definition of a second (*SN: 3/24/21*). The length of a second is currently defined using an earlier generation of atomic clocks that are not as precise as newer ones like those used in the two new studies (*SN: 5/20/19*).

"There is a very bright future for the clocks," Safronova says.

Source: **An atomic clock measured how general relativity warps time across a millimeter**