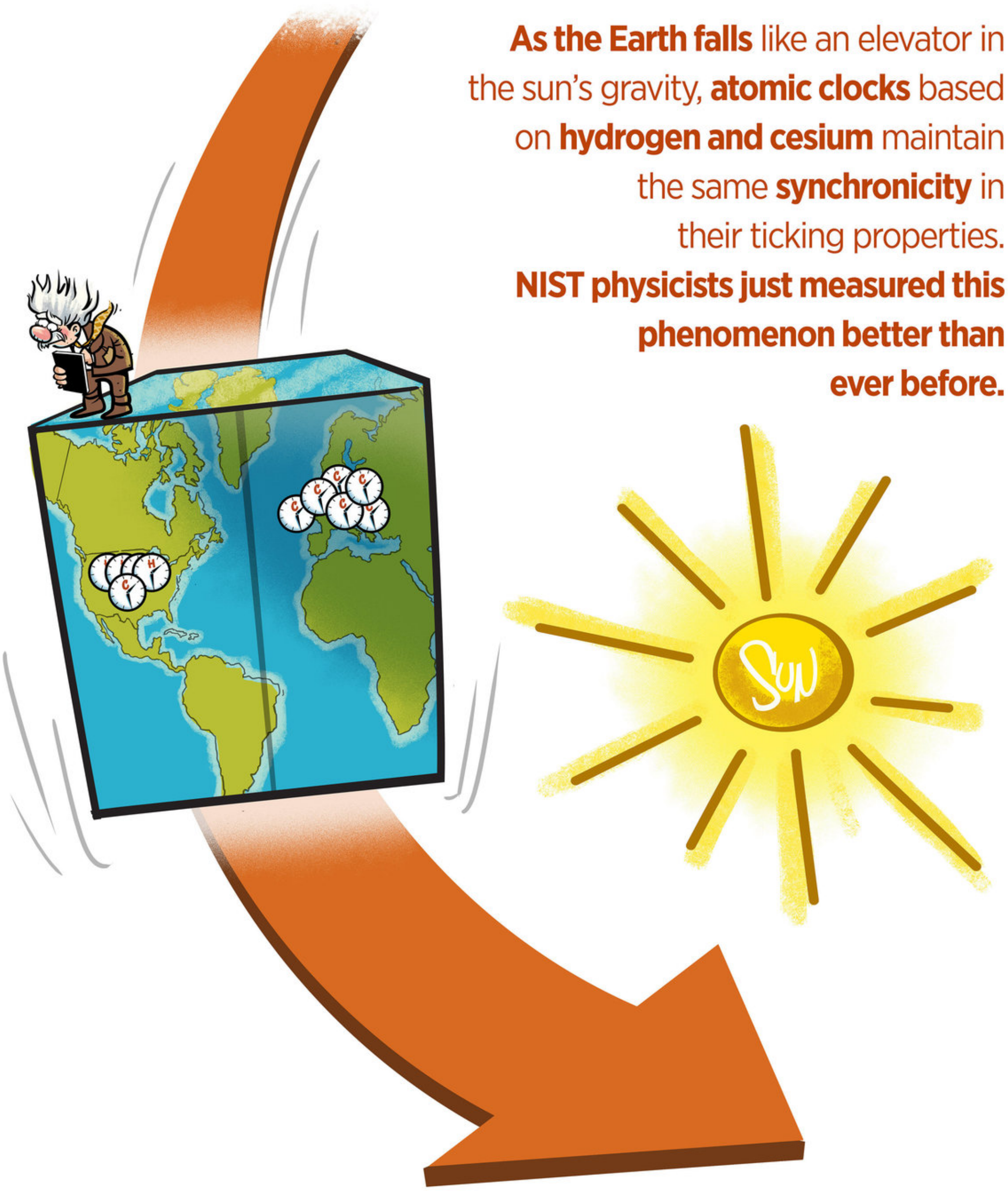
NIST atomic clock comparison confirms key assumptions of 'Einstein's elevator'

June 4 2018



Einstein's elevator: As the Earth falls like an elevator in the sun's gravity, atomic clocks based on hydrogen and cesium maintain the same synchronicity in their ticking properties. NIST physicists just measured this phenomenon better than ever before. Credit: K. Rechin/NIST

By comparing different types of remote atomic clocks, physicists at the National Institute of Standards and Technology (NIST) have performed the most accurate test ever of a key principle underlying Albert Einstein's famous theory of general relativity, which describes how gravity relates to space and time.

The NIST result, made possible by continual improvements in the world's most accurate atomic clocks, yields a record-low, exceedingly small value for a quantity that Einstein predicted to be zero.

As described in a *Nature Physics* paper posted online June 4, NIST researchers used the solar system as a laboratory for testing Einstein's thought experiment involving Earth as a freefalling elevator. Einstein theorized that all objects located in such an elevator would accelerate at the same rate, as if they were in a uniform gravitational field—or no gravity at all. Moreover,he predicted, these objects' properties relative to each other would remain constant during the elevator's free-fall.

In their experiment, the NIST team regarded Earth as an elevator falling through the Sun's gravitational field. They compared recorded data on the "ticks" of two types of atomic clocks located around the world to show they remained in sync over 14 years, even as the gravitational pull on the elevator varied during the Earth's slightly off-kilter orbit around the sun.Researchers compared data from 1999 to 2014for a total of 12 clocks—four hydrogen masers(microwave lasers) in the NIST time scale with eight of the most accurate cesium fountain atomic clocks operated by metrology laboratories in the United States, the United Kingdom, France, Germany and Italy.

The experiment was designed to test a prediction of general relativity, the principle of local position invariance (LPI), which holds that in a falling elevator, measures of nongravitational effects are independent of time and place. One such measurement compares the frequencies of electromagnetic radiation from atomic clocks at different locations. The researchers constrained the violation of LPIto a value of 0.00000022 plus or minus 0.00000025—the most miniscule number yet, consistent with general relativity's predicted result of zero, and corresponding to no violation. This means the ratio of hydrogen to cesium frequencies remained the same as the clocks moved together in the falling elevator.

This result has five times less uncertainty than NIST's best previous measurement of the LPI violation,translating to five times greater sensitivity. That earlier 2007 result, from a 7-year comparison of cesium and hydrogen atomic clocks, was 20 times more sensitive than the previous tests.

The latest measurement advance is due to improvements in several areas, namely more accurate cesium fountain atomic clocks, better time transfer processes (which enable devices at different locations to compare their time signals), and the latest data for computing the position and velocity of Earth in space, NIST's Bijunath Patla said.

"But the main reason we did this work was to highlight how atomic clocks are used to test fundamental physics; in particular, the foundations of general relativity," Patla said. "This is the claim made most often when clockmakers strive for better stability and accuracy. We tie together tests of general relativity with atomic clocks, note the limitations of the current generation of clocks, and present a future outlook for how next-generation clocks will become very relevant."

Further limits on LPI are unlikely to be obtained using hydrogen and cesium clocks, the researchers say, but experimental next-generation clocks based on optical frequencies, which are much higher than the frequencies of hydrogen and cesium clocks, could offer much more sensitive results. NIST already operates a variety of these clocks based on atoms such as ytterbium and strontium.

Because so many scientific theories and calculations are intertwined, NIST researchers used their new value for the LPI violation to calculate variations in several fundamental "constants" of nature, physical quantities thought to be universal and widely used in physics. Their results for the light quark mass were the best ever, while results for the fine structure constant agreed with previously reported values for any pair of atoms.

More information: N. Ashby, T.E. Parker and B.R. Patla. 2018. A null test of general relativity based on a long-term comparison of atomic transition frequencies. *Nature Physics*. June 4. Advance Online Publication, DOI: 10.1038/s41567-018-0156-2 , www.nature.com/articles/s41567-018-0156-2

Provided by National Institute of Standards and Technology