Top-precision optical atomic clock starts ticking

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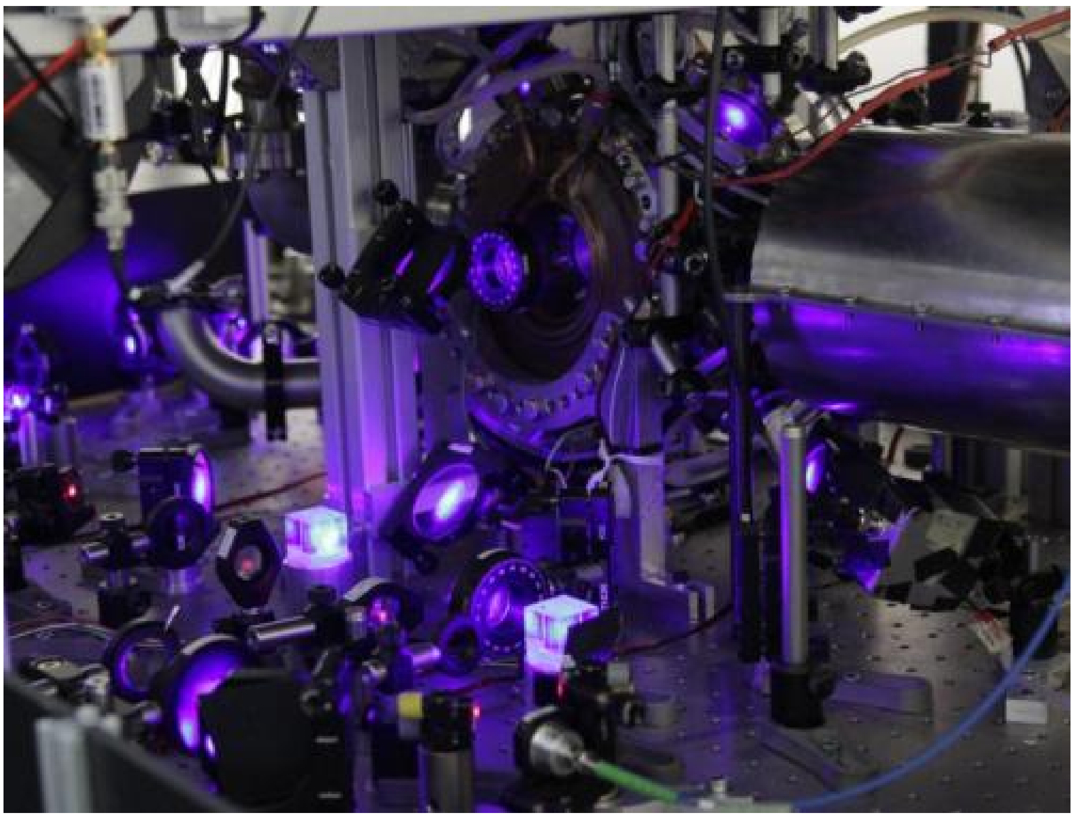

An atomic standard, one of the main elements of the optical atomic clock, now operating at the National Laboratory of Atomic, Molecular and Optical Physics (KL FAMO) in Toruń, Poland. Credit: Source: NCU, Anna Bielawiec-Osińska

A state-of-the-art optical atomic clock, collaboratively developed by scientists from the University of Warsaw, Jagiellonian University, and Nicolaus Copernicus University, is now "ticking away" at the National

Laboratory of Atomic, Molecular and Optical Physics in Toruń, Poland. As the first of its kind in Poland and one of just a handful of clocks of this caliber in the world, the new clock will keep track of the passage of time with extraordinary precision.

Physicists from Warsaw, Toruń, and Cracow have constructed an atomic clock that is one of just a few of its kind in the world - already now, at an early stage of operation, it has most likely become Poland's most precise clock. Occupying four rooms at the National Laboratory for Atomic, Molecular and Optical Physics (KL FAMO) in Toruń, it was built and launched into operation by the Polish Optical Atomic Clock (POZA) consortium formed by the University of Warsaw (UW, project coordinator), Nicolaus Copernicus University (NCU) and Jagiellonian University (JU).

The theoretical stability of the new clock, stemming from the advanced physical mechanisms it harnesses, means that it would take tens of billions of years for an error of a single second to accumulate - which is several times longer than the time that has passed since the Big Bang.

"We still have a way to go to achieve such great stability. Like every refined measurement device, our clock requires gradual, painstaking calibration, with certain improvements constantly being made. But already now, at the very beginning of our work, we have achieved greater stability than that required for clocks of this type by the International Bureau of Weights and Measures in Paris: we have an error of less than one second in tens of millions of years," says Dr. Roman Ciuryło, the director of KL FAMO.

Optical atomic clocks consist of an atomic standard, an optical comb, and an ultra-precise laser. The frequency of the light generated by the laser is precisely tuned to match the difference in energy between strictly defined levels in the atoms trapped inside the atomic standard. Time is then measured by counting the oscillations in the electromagnetic field of the tuned and stabilized laser light. The frequency of this laser light wave is nevertheless so high that counting individual "ticks" of the clock is beyond the capacity of modern electronics. This problem is solved using an optical frequency comb, a laser that generates very short pulses lasting mere femtoseconds (a millionth of a billionth of a second), which act like a toothed gear, translating the optical frequencies into lower, radio frequencies. These pulses serve as the optical counterpart of a ruler, whose intervals can be synchronized (with a matching rhythm) to the frequency of the laser light tuned to the atomic standard.

"Truly precise time measurements demand that the results be constantly compared against many other clocks. That is why, right from the start, we built two completely independent atomic standards. Readings from the two standards enable us to fine-tune the 'ticking' of the clock as a whole with significantly greater precision," says Dr. Michał Zawada (KL FAMO, NCU).

Both atomic standards in the KL FAMO system operate with strontium 88 atoms, but in order to exclude repetitive errors, in one of them strontium 87 atoms can be used as well. The strontium atoms in each standard are isolated from the environment and from one another: cooled to a temperature below 10 microkelvins, they are situated inside an ultrahigh vacuum chamber and immobilized in a specially constructed optical trap generated by the beam of a supplementary laser.

To read the passage of time off the strontium atoms, they are exposed to the red light of the main, ultra-stable laser, with a frequency of approx. 429 terahertz. After the energy of the laser light is fine-tuned to match the transition in the atoms, the frequency of the laser beam is translated by means of the optical frequency comb into radio frequencies, at around 250 megahertz. At this stage the individual "ticks" of the clock are counted by the corresponding electronic apparatus.

"The stability of such a clock is one thing, whereas its precision is something else. To ascertain the latter, in other words to be able to compare our readings to those of the existing time standards, we have started a collaboration with the Central Office of Measures in Warsaw and the Borowiec Astrogeodynamic Observatory," stresses Prof. Czesław Radzewicz (UW Faculty of Physics).

Time signals are transmitted between the laboratories in Toruń, Warsaw, and Borowiec via fiber-optic cables made available by the PIONIER academic network and the telecoms company Orange, under the OPTIME project financed by the National Centre for Research and Development. The network consists of telecommunications fiber-optic cables and dedicated transmission and amplification equipment developed by engineers from the Department of Electronics at University of Science and Technology in Cracow.

"Merely having the Toruń-based clock included into the pool of existing clocks constituting the time standard has boosted the precision of that standard. In practice that means that our clock will also make a contribution to the future definition of the second," says Dr. Zawada.

Because the new clock has started operating quite recently, the physicists working on the project have not yet finished the tests required to precisely identify all the device's properties. The data collected so far, however, does suggest that at the current stage of operations the clock in Toruń is already the most stable and most precise in Poland.

"The basis for this success lies in the excellent subdivision of responsibilities and the smooth collaboration between the experimental groups from all three universities. The project, after all, represented a serious challenge also in the logistical sense. One of the two atomic standards was built in Cracow and, after being initially set into operation and tested there, was brought to Toruń. The extremely sensitive apparatus survived that trip unscathed," says Prof. Wojciech Gawlik (JU). He goes on to note: "As a result of our cooperative efforts, Poland now has a unique instrument which, apart from making extremely precise measurements of time, can also be used to carry out highly refined experiments in atomic physics, molecular physics, and quantum optics."

High-precision time measurements play an important role in many fields of science and technology. The most advanced clocks can help physicists to test such fundamental aspects of reality as the time variability of physical constants, to very precisely verify the predictions of the general theory of relativity, and also to search for dark matter in the Universe. Atomic clocks of the previous generation, with significantly lower precision, are currently being used in applications including satellite navigation systems, high-capacity wireless networks (wi-fi), ensuring the security of bank communications, and also taking measurements of the Earth's gravitational field, yielding insight into its internal geological structure.

Provided by University of Warsaw