Transportable optical clock used to measure gravitation for the first time

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The transportable strontium optical lattice clock in the Modane Underground Laboratory. Credit: Lisdat/PTB

A European collaboration involving clock experts from the National Physical Laboratory (NPL), the Physikalisch-Technische Bundesanstalt

(PTB) and the Istituto Nazionale di Ricerca Metrologica (INRIM) has used a transportable optical atomic clock to measure gravitation for the first time. The results of the experiment were published in *Nature Physics*.

Until now, such delicate clocks have been restricted to laboratories at a few major research institutions. However, researchers at PTB have developed a transportable strontium optical lattice clock for performing measurements in the field. The transportable clock was driven in a vibration-damped and temperature-stabilised trailer to the French Modane Underground Laboratory (LSM). The multidisciplinary lab is located in the middle of the Fréjus road tunnel between France and Italy.

There, the team measured the gravity potential difference between the exact location of the clock inside the mountain and a second clock at INRIM located 90 km away in Torino, Italy, at a height difference of about 1,000 m.

The accurate comparison of the two clocks was made possible using a 150 km-long optical fibre link set up by INRIM and a frequency comb from NPL to connect the clock to the link. Researchers from Leibniz Universität Hannover also determined the gravity potential difference using conventional geodetic techniques, and the two measurements were shown to be consistent.

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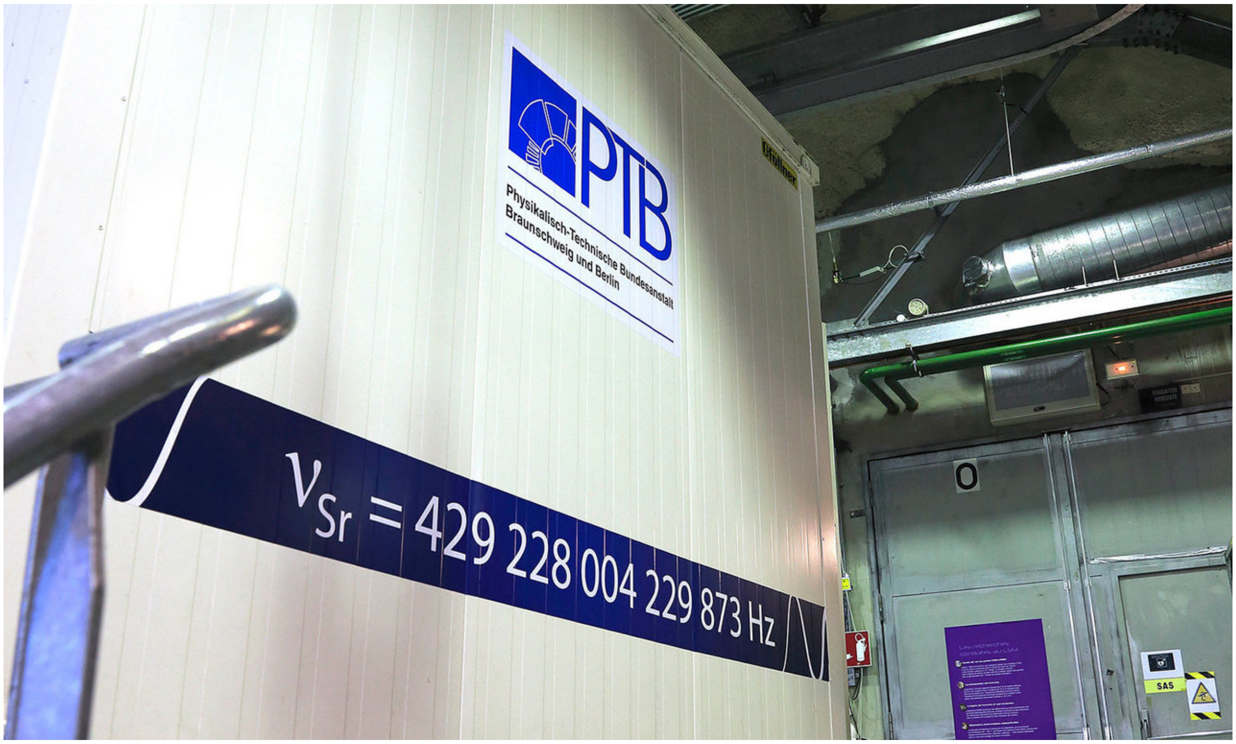


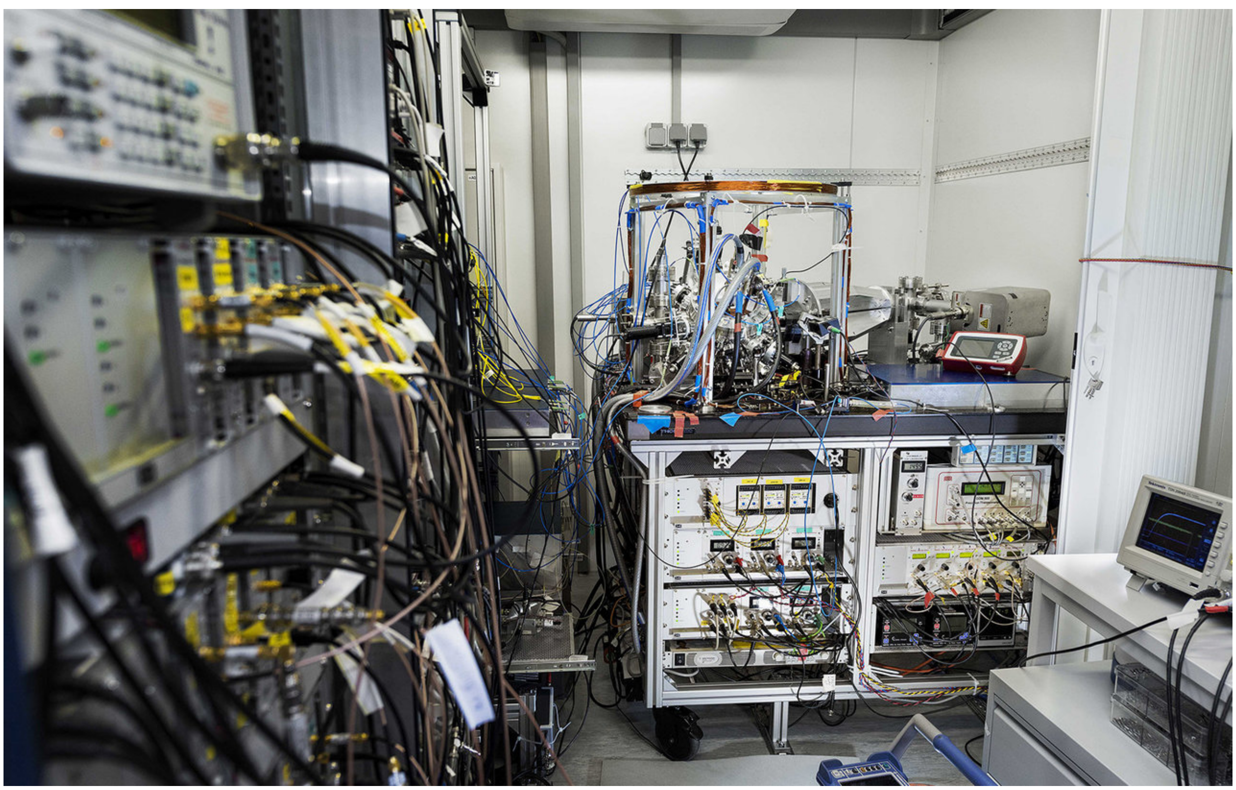
The vibration-damped and temperature-stabilised trailer with PTB's optifcal atomic clock in the French Modane Underground Laboratory (LSM). Credit: Lisdat/PTB

With improvements to the accuracy of the transportable optical clock, this technique has the potential to resolve height differences as small as 1 cm across the Earth's surface. The advantage of using optical clocks is that they can make measurements at specific points in contrast to satellite-based measurements, such as GRACE and GOCE, which average the gravity potential over length scales of about 100 km.

This novel method could lead to higher-resolution measurements of the Earth's gravity potential, allowing scientists to monitor continental height changes related to sea levels and the dynamics of ocean currents with unprecedented accuracy. It will also lead to more consistent national height systems.

Currently, different countries measure the Earth's surface in the same way, but relative to different reference levels. This has led to problems—one such being the Hochrhein Bridge between Germany and Switzerland, where construction on each side used different sea level calculations, leading to a 54 cm discrepancy between the two sides.

Achieving consistency between national height systems will prevent costly mistakes in engineering and construction projects. Improved measurements of gravity potential may also help to improve our understanding of geodynamic effects associated with mass changes under the Earth's surface.



Inside view of the trailer with PTB's transportable optical atomic clock. Credit:

Physikalisch-Technische Bundesanstalt (PTB)

This technology will also measure changing sea levels in real time, allowing researchers to track seasonal and long-term trends in ice sheet masses and overall ocean mass changes. Such data provides critical input into models used to study and forecast the effects of climate change.

Helen Margolis, fellow in optical frequency standards and metrology at NPL, said, "Our proof-of-principle experiment demonstrates that optical clocks could provide a way to eliminate discrepancies and harmonise measurements made across national borders. One day, such technology could help to monitor sea level changes resulting from climate change."

Group leader Christian Lisdat at PTB, said, "Optical clocks are deemed to be the next generation of atomic clocks—operating not only in laboratories but also as mobile precision instruments."

Davide Calonico at INRIM, said, "We demonstrated that optical clocks are valuable quantum sensors, and their quantum technology is beneficial outside primary metrology, in geodesy. Together, optical clocks and optical fiber links offer the possibility to access new and fascinating scientific investigation"

Heiner Denker at Leibniz Universität Hannover, said, "The newly developed optical clocks have the potential to revolutionise geodetic height determination, as they can overcome some of the limitations of classical geodetic techniques. Optical clocks could help to establish a unified world height reference system with significant impact on geodynamic and climate research."

More information: Jacopo Grotti et al, Geodesy and metrology with a transportable optical clock, *Nature Physics* (2018). DOI: 10.1038/s41567-017-0042-3

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