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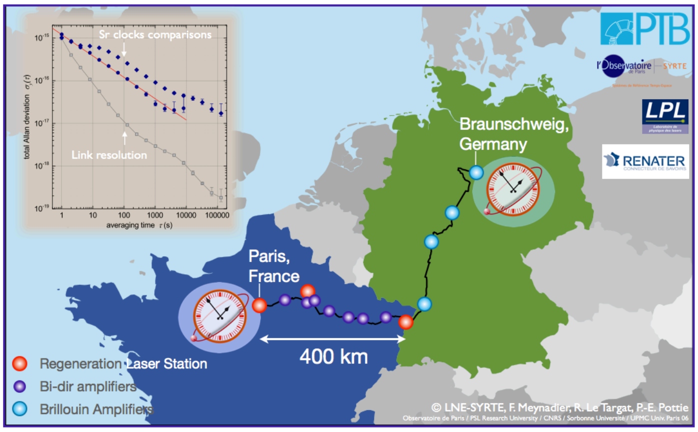
Optical fibre link opens a new era of time-frequency metrology



French physicists at Systèmes de référence temps-espace (CNRS/Observatoire de Paris/UPMC, associated to LNE) and at Laboratoire de physique des lasers (CNRS/ Université Paris 13) and German physicists at Physikalisch-Technische Bundesanstalt established a fully optical connection between France and Germany with a crucial support of RENATER: optical frequencies can now be compared accurately through a 1400 km optical fiber link, connecting with unprecedented resolution the national metrology institutes LNE-SYRTE and PTB, where the most accurate Sr optical clocks in Europe are operated. The new link is used to compare two optical lattice clocks distant by a geographical distance of 700 km with an unrivaled fractional uncertainty of 5 × 10^{-17}. The absolute frequency of the two optical clocks are found in agreement within their uncertainty budgets. This comparison is 20 times more precise than what was achievable so far by using GPS, and the measurement is 10 000 faster for the same resolution. It paves the way to future applications in fundamental physics, astrophysics and geoscience.

Over the last years, spectacular improvements were made on optical atomic clocks, where a laser is used to probe a reference transition between two quantum levels of an atom. These optical clocks are now up to 100 times more precise than the microwave clocks used to define the SI second. If clocks can be compared locally with high precision, comparing distant optical clock without degradation of their performance was not possible since conventional satellite transmission lack about two order of magnitude in resolution to do so.

The idea of the researchers is simple : the clock's laser frequency can be related to the frequency of a transfer laser operated at the telecommunication wavelength of 1.5 micrometer, the laser being injected into an long-haul optical fiber link connecting the two optical clocks. The link was established thanks to a crucial partnership with the French National research and Education Network RENATER, where the metrological signal is carried from Paris to Strasbourg in parallel of the data traffic, and interconnected to the german part

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of the link. On the German side, the link from Strasbourg to Braunschweig is using a commercially rented optical fiber and with the facilities provided by the German National Research and Education Network (DFN). Altogether the researchers built so a 1400-km long optical fiber link.

The technical challenges are to overcome the attenuation and the noises that arise with the propagation. For that purpose special amplifiers and regeneration laser stations were designed by the researcher's teams of PTB, LNE-SYRTE and LPL, and set-up along the link, so that these fluctuations are made negligible. They showed that this optical method with an optical fiber reaches a resolution of 10^{-19}, i.e. 10 000 times better than GPS, largely good enough to compare the quantum clocks operated at SYRTE and PTB. The level of resolution obtained by this international collaboration is simply out-of-reach to any satellite methods to date, by several orders of magnitude, and last but not least, allows much faster measurements.

The link is used to compare two optical lattice clocks, using cold Sr atoms. The comparison represents the first frequency comparison between two optical clocks across national borders: the fully independent clocks agree with an unrivaled fractional uncertainty of 5×10^{-17}, demonstrating the perfect control of several physical effects that can affect the clock accuracy. Comparing optical clocks at the highest resolution opens the way to a wide range of very sensitive physical experiments. In the future, the precision of these clocks should exceed 10^{-18}, i.e. 1 part to the billion of a billion. At that level of precision, the comparison of these clocks will lead to a sensitivity in height better than the centimeter, what could surpass the best geodetics methods to date, and opens the field of chronometric geodesy. Thus these quantum clocks become ultra-sensitive gravitational sensors.

The scientific impact of the ability to disseminate optical frequency will be very important for many applications, as for instance tests of general relativity using clocks on Earth and on board of the ISS (future space mission ACES), for fundamental physics as the search for dark matter, for the synchronization of experiments over very long base lines, and for ultra-precise measurements. The REFIMEVE+ project is at work in France to disseminate optical frequency standard to about 20 physical laboratories, using 4000 km of the fiber network of RENATER. Industrial grade of the scientific equipments used on the link Paris-Strasbourg are developed for that purpose by a consortium of three French SMEs, MuQuans (coordinator), Syrlinks and Keopsys. At the European level this successful collaboration is a first step towards a European network of atomic clocks, where the EU could play a major role for the future re-definition of the unit of time.

The following partners are involved: Physikalisch-Technische Bundesanstalt (PTB), Laboratoire de Physique des Lasers (Université Paris 13/ Sorbonne Paris Cité/CNRS), LNE-SYRTE (Observatoire de Paris/PSL Research University/CNRS/Sorbonne Université/UPMC Univ. Paris 06/ Laboratoire National de Métrologie et d'Essais), RENATER, Laboratoire de Photonique Numérique et Nanosciences (Institut d'Optique Graduate School, CNRS, Université de Bordeaux), and GIP RENATER (CNRS/CPU/CEA/INRIA/CNES/INRA/INSERM/ONERA/CIRAD/IRSTEA/IRD/ BRGM/MESR).

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