Optical clocks for a new definition of the second

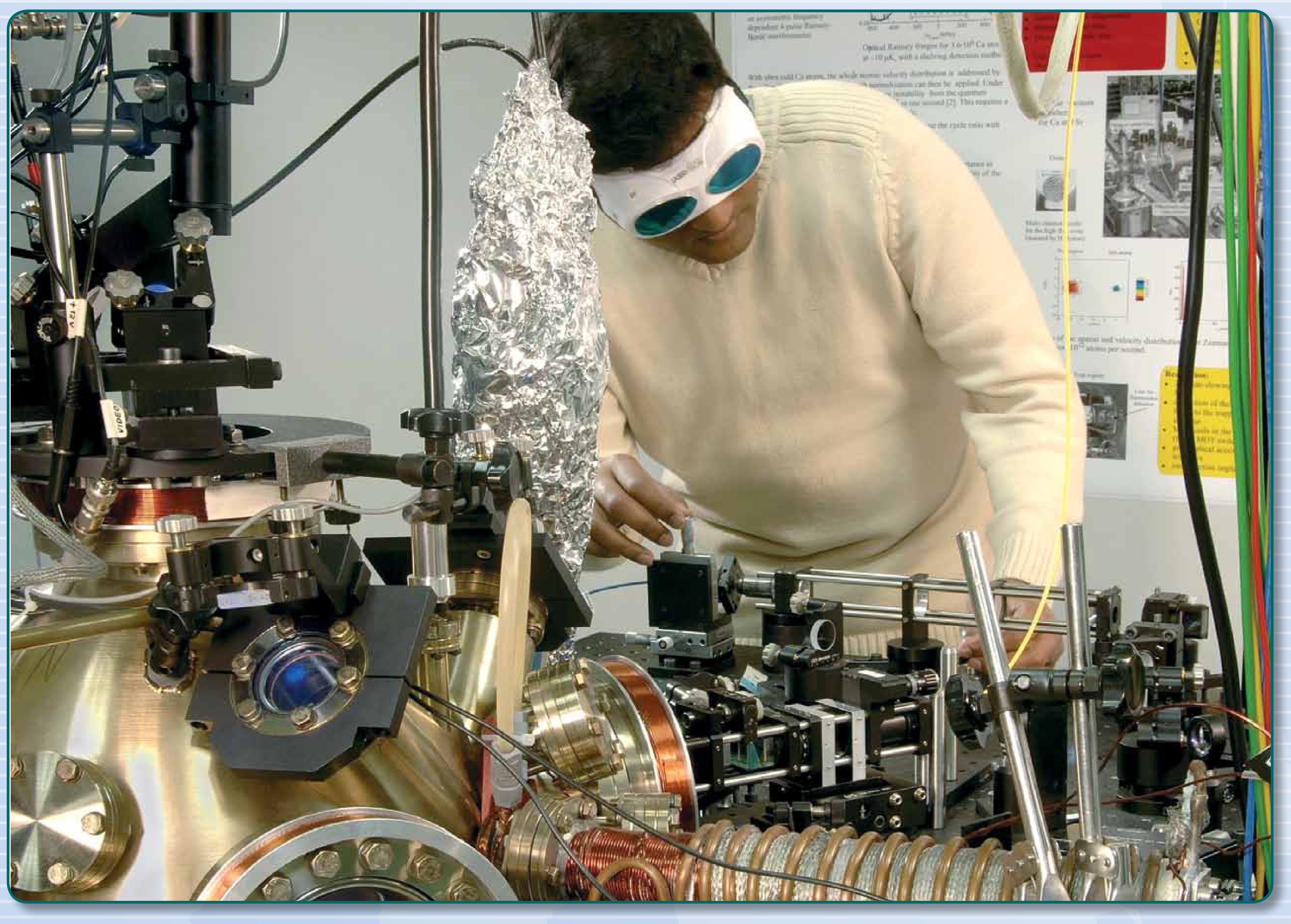
EURAMET
European Association of National Metrology Institutes

The need for the project

Ultra high performance optical clocks now outperform the best microwave standards based on caesium (Cs) atoms, which are presently used to define the second. A new definition of the second is therefore needed so that it remains based on state-of-the-art technology.

The principle underlying the operation of these optical clocks is the use of an optical lattice to freeze the atomic motion. Atoms are strongly confined in a series of potential wells formed by the interference of lasers. By using a large number of atoms simultaneously, this type of clock has superior potential in terms of ultimate frequency stability - presumably better than 10^{-18} after one day of integration.

The aim of this project was a detailed investigation of a possible optical resonance for the new definition of the second: the $^1S_0$-$^3P_0$ transition of atomic strontium (Sr).



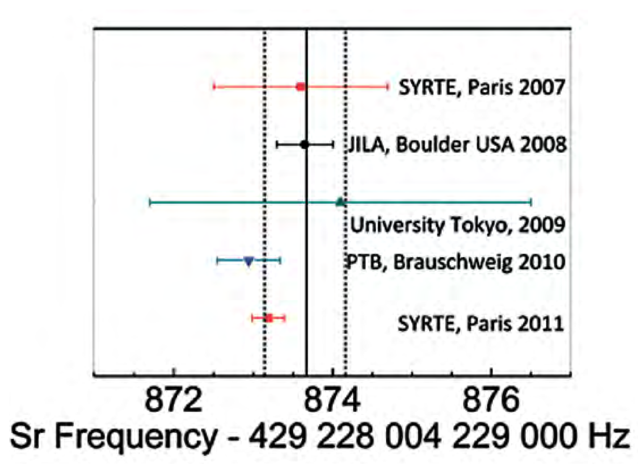
The vacuum system of PTB's strontium lattice clock.

Technical achievements

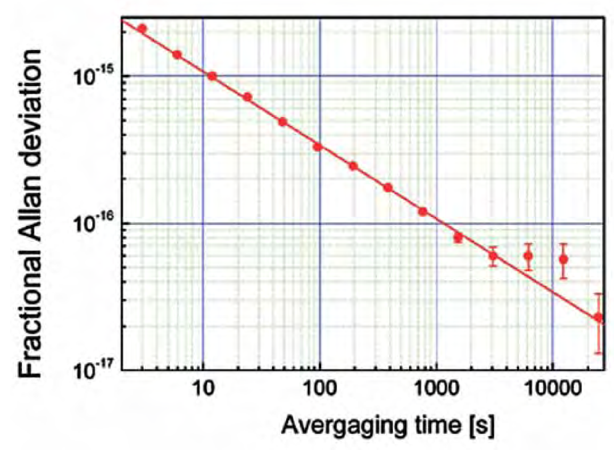
Both the accuracy and stability of optical clocks have been improved to a level significantly better than the best Cs fountain primary standards. By using optical resonances, as narrow as 3 Hz, corresponding to a quality factor exceeding 10^{14}, and performing the first high performance comparison of Sr lattice clocks, a fractional frequency stability as good as 5×10^{-17} was demonstrated after one hour of averaging time.

The most relevant frequency shifts were studied in detail both experimentally and theoretically. This included the residual effect of the lattice field, the effect of collisions between cold atoms, and the effect of the blackbody field radiated by the environment surrounding the atoms. This resulted in a fractional frequency accuracy of approximately 10^{-16}.

Comparisons with a large set of primary standards were performed, resulting in a measurement of the Sr clock frequency in SI units with unprecedented accuracy. Methods were developed for future improvements, such as the demonstration of a non-destructive detection method for the optimisation of the clock frequency stability, as well as technological developments for future transportable or space-bound clocks.



Frequencies of the ^{87}Sr clock transition measured by different laboratories. The vertical line gives the recommendation for ^{87}Sr as secondary representation of the second with its uncertainty (dashed lines). The two points PTB 2010 and SYRTE 2011 represent the best optical frequency measurement to date.



Allan deviation of the comparison between two independent Sr lattice clocks, demonstrating for the first time a mid-term stability in the low 10^{-17} range.

Advanced optical clocks

Developed three Sr clocks that can be used as a common reference to repeatedly measure the other clock transitions under investigation at National Metrology Institutes.

The project demonstrated the accuracy and stability of these optical clocks and increased knowledge of collisions between cold atoms, atomic motion in the quantum regime and atom-field interactions.

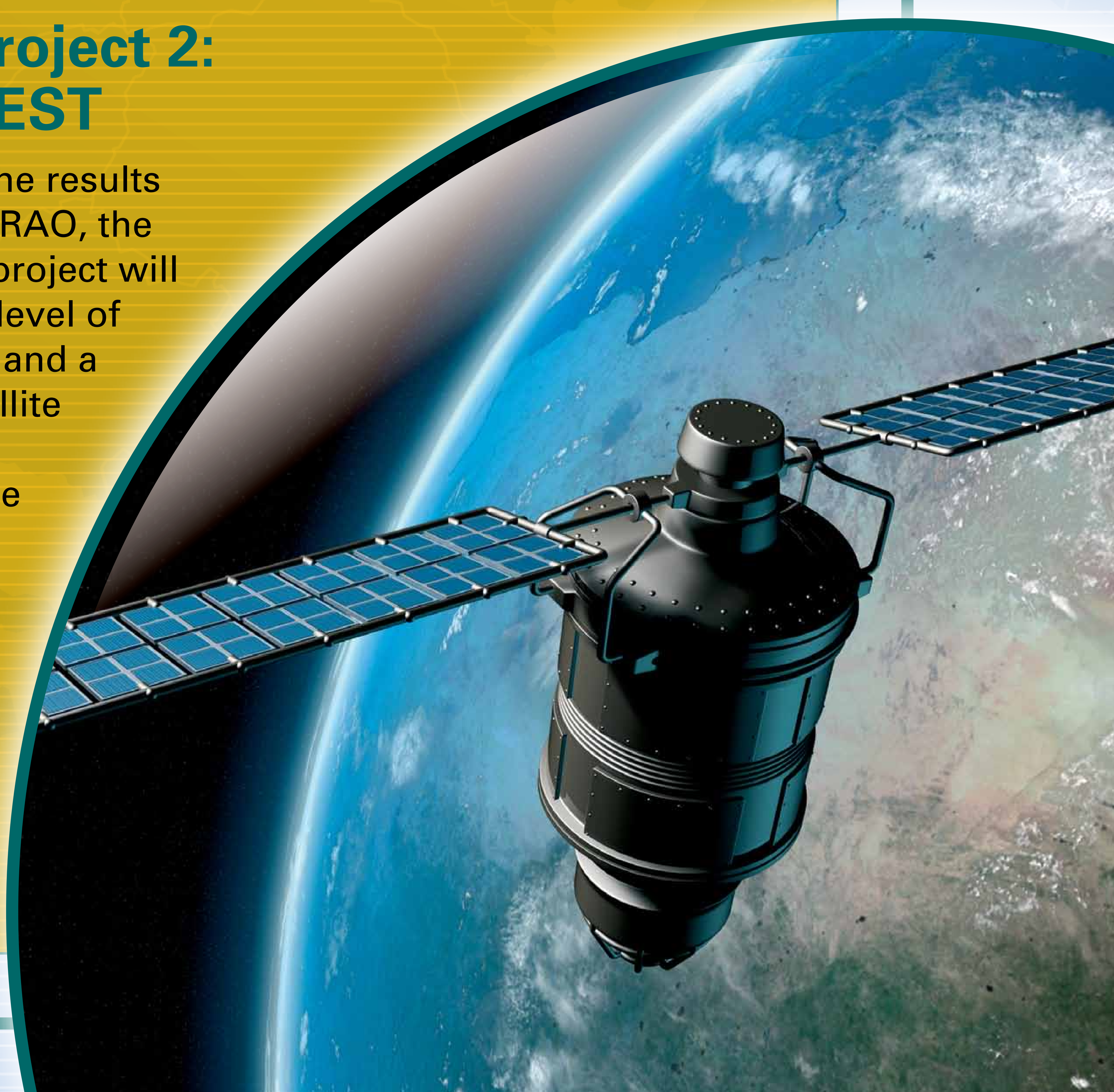
The clocks will also be at the heart of two future space missions: ACES/PHARAO and STE-QUEST.

Space project 1: ACES/PHARAO

Due to commence in 2014, over 18-36 months, it aims to demonstrate relative geodesy, by mapping the Earth's gravitational field using atomic clocks as sensors of the gravitational redshift. The clocks will be used as references for the evaluation of the gravitational field difference between different locations.

Space project 2: STE-QUEST

Building on the results of ACES/PHARAO, the STE-QUEST project will use a higher level of performance and a different satellite orbit. This mission is due to take place after 2020.



Joint Research Project (JRP) Short Name: OCS • JRP-Coordinator: Pierre Lemonde (CNRS) • JRP-Partners: CNRS (France), INRIM (Italy), MIKES (Finland), NPL (UK), OBSPARIS (France), PTB (Germany)

The research within this EURAMET joint research project received funding from the European Community's Seventh Framework Programme, ERA-NET Plus, under the iMERA-Plus Project - Grant Agreement No. 217257

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union