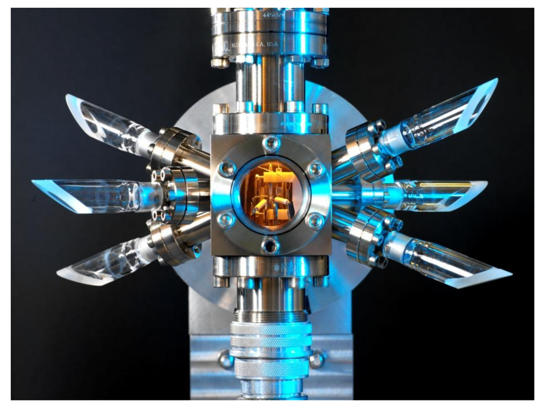
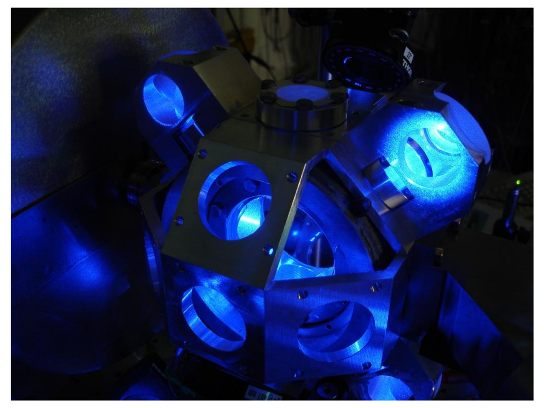
International timescales with optical clocks (ITOC)

H. S. Margolis, D. Calonico, P. Delva, H. Denker, S. Falke, R. M. Godun, D. Piester, J. Achkar, S. Bize, J. Gersl, P. Gill, L. A. M. Johnson, F. Levi, T. Lindvall, C. Lisdat, L. Lorini, M. Merimaa, M. Pizzocaro, S. L. Shemar, U. Sterr, L. Timmen, S. Vogt, C. Voigt, S. Weyers and P. B. Whibberley

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Rationale for the project

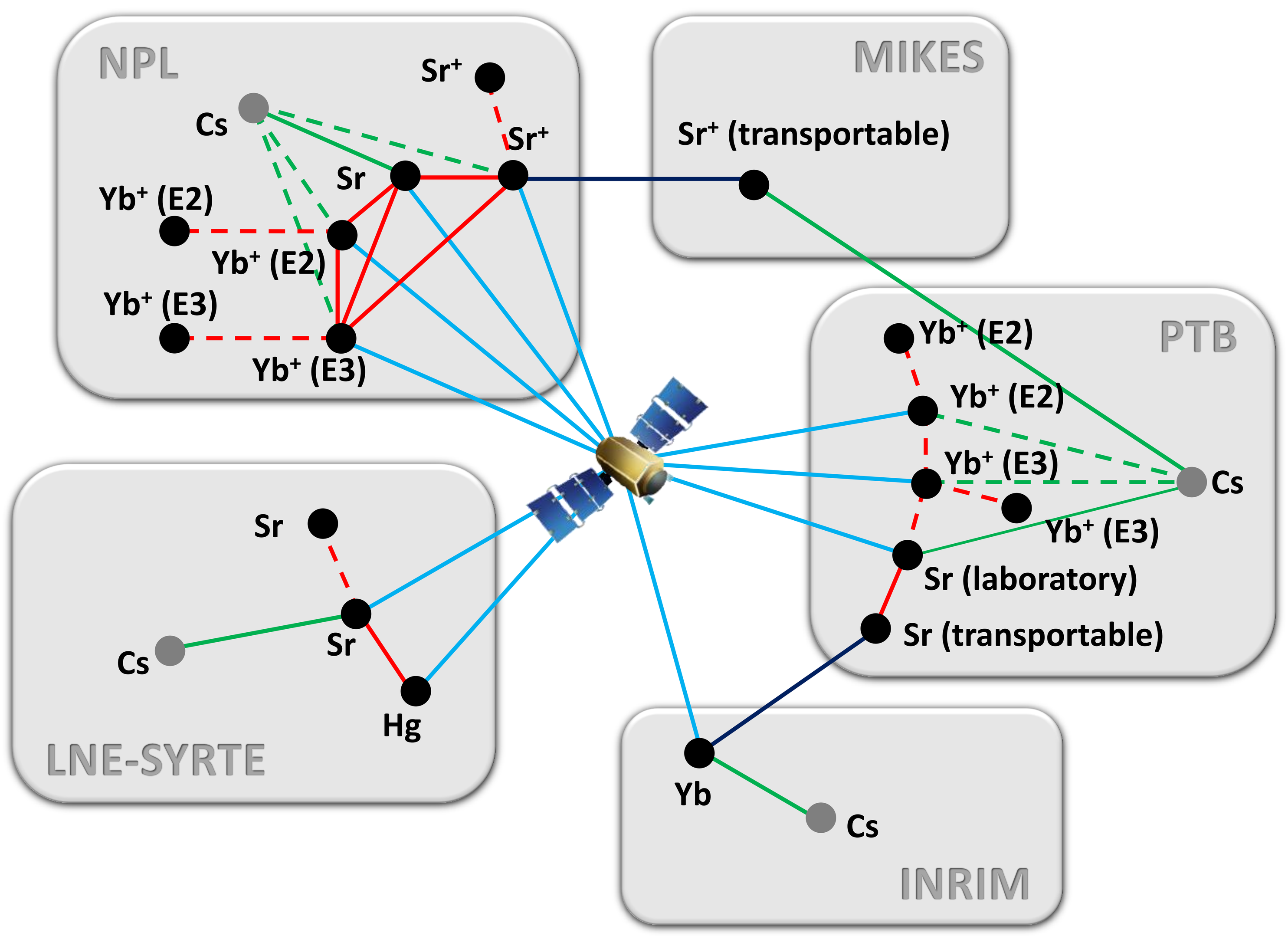




The most advanced optical atomic clocks have now reached levels of stability and accuracy that surpass the performance of the best caesium fountain primary standards. However before an optical **redefinition of the SI second** can be implemented, it is necessary to:

- Develop **improved methods for comparing optical clocks** developed in different laboratories;
- Carry out a **coordinated programme of clock comparisons** to build confidence in the performance of the optical clocks, to anchor their frequencies to the current definition of the second, and to establish the leading contenders for a redefinition;
- **Evaluate relativistic effects** influencing comparisons between clocks at an improved level of accuracy, including the gravitational redshift of the clock transition frequency;
- Establish a framework and procedures for the optical clocks to be **integrated into international timescales**.

Coordinated programme of optical clock comparisons



Key aspects of the programme:

- It involves all European NMIs developing optical atomic clocks;
- Both major types of optical clock technology (optical lattice clocks and trapped ion optical clocks) are represented;
- The comparison matrix includes some redundancy to allow self-consistency checks to be carried out;
- The analysis will allow optimised values to be derived for optical frequency ratios and absolute frequencies;
- Comparisons carried out within other projects will be included in the analysis wherever possible.

Local optical frequency comparisons using femtosecond combs
(comparisons between co-located clocks will lead to the highest levels of stability and accuracy)

Frequency comparisons using transportable optical clocks
(both optical lattice clocks and trapped ion optical clocks will be investigated)

Optical frequency comparisons using broad bandwidth TWSTFT
(goal is a factor of ten improvement in stability compared to current state-of-the-art satellite-based techniques)

Absolute frequency measurements with uncertainty limited by caesium primary standards

Relativistic timescales and geodesy

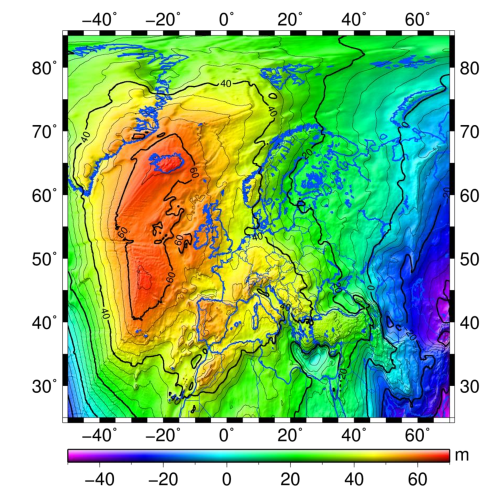
To support the clock comparison programme, a complete evaluation will be made of all relativistic effects influencing time and frequency comparisons at the 10^{-18} level of accuracy.

Relativistic effects affecting time and frequency transfer links:

- Broadband TWSTFT (effects related to satellite velocity, e.g. first- and second-order Doppler effect, Sagnac effect, path variation effects);
- Optical fibre links (new methods are required to account for signal propagation in a medium with refractive index $n > 1$);
- Continuously operating transportable clocks (shifts due to their velocity and the gravitational potential experienced along their trajectory).

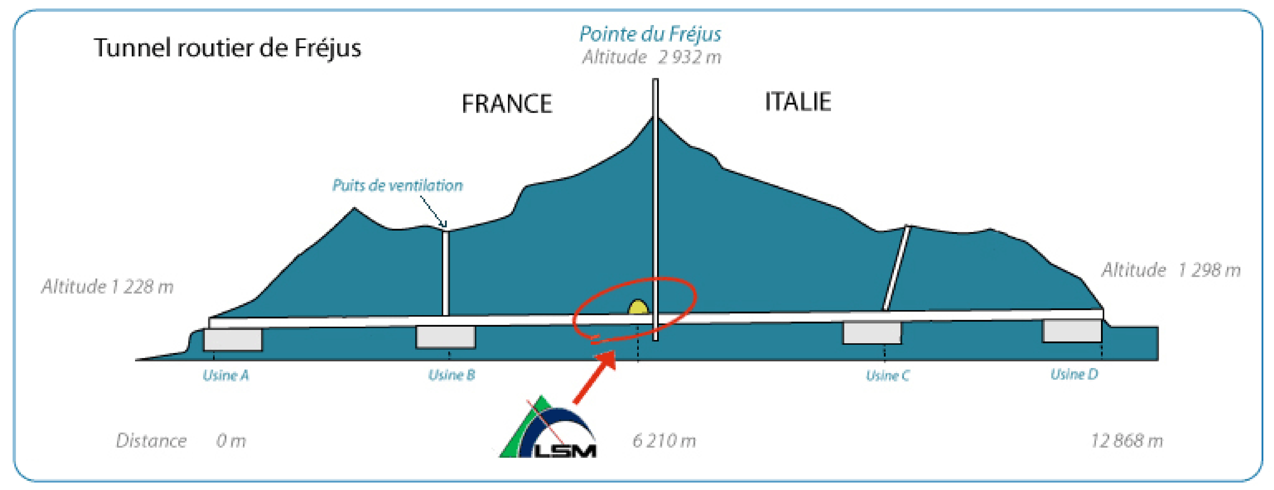
Gravitational redshift corrections:

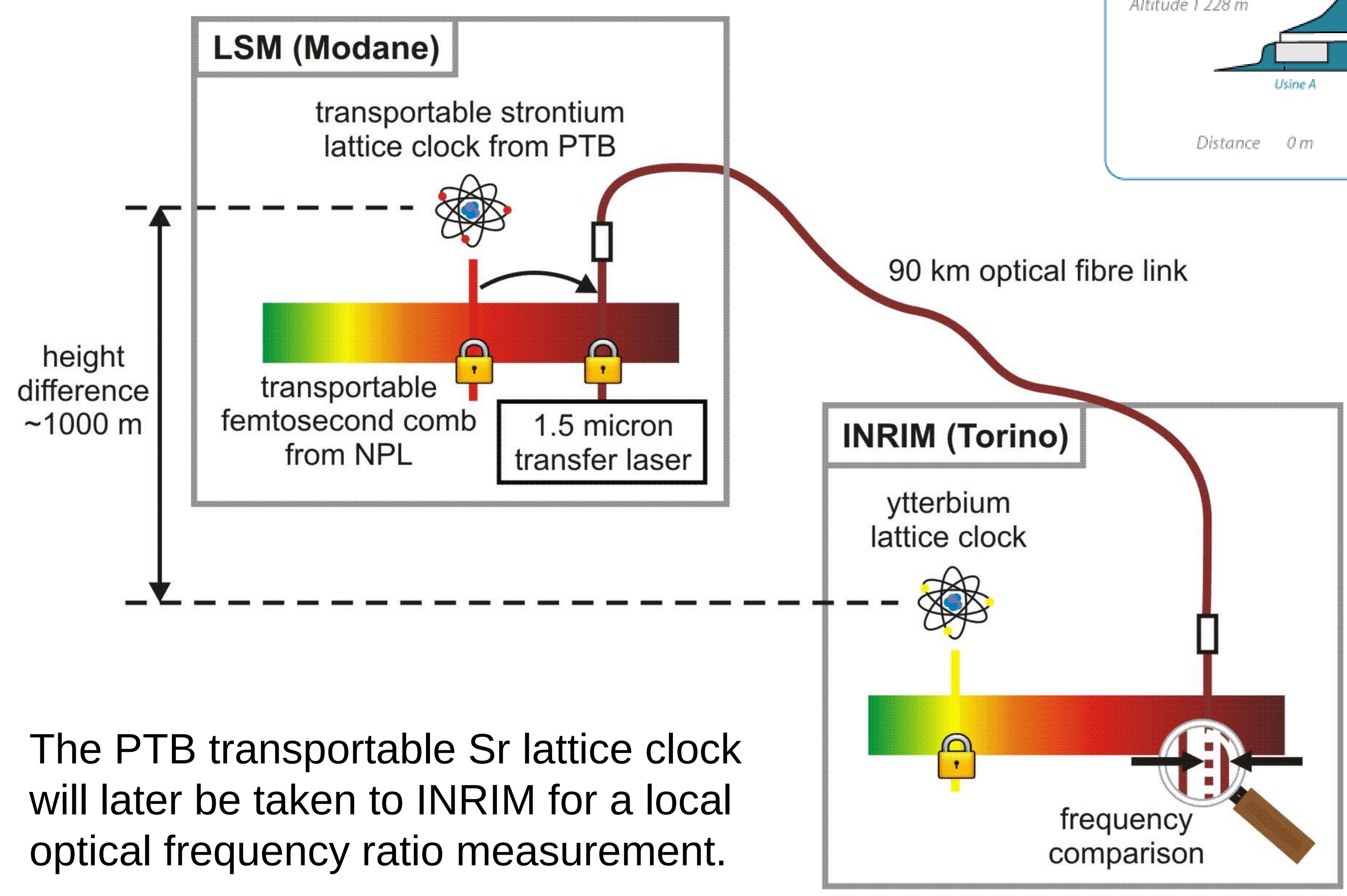
- Design of setups to determine the static gravity potential at all clock locations (potential differences for clock comparisons, absolute potential values for timescales);
- Development of a refined European geoid model including gravity observations around all relevant clock sites;
- Investigation of time-variable components of the gravity potential, e.g. due to tides.



Proof-of-principle clock-based geodesy experiment

Aim: To demonstrate that optical clocks can be used to measure gravity potential differences over medium-long baselines with high temporal resolution.





The PTB transportable Sr lattice clock will later be taken to INRIM for a local optical frequency ratio measurement.

Height difference ~ 1000 m

→ Gravitational redshift ~ 10^{-13}

Targets:

Clock accuracy 5×10^{-17}

Clock instability $1 \times 10^{-15}\ \tau^{-1/2}$

Optical link instability $10^{-14}\ \tau^{-1}$

→ resolution of tens of cm in a few hours

NPL National Physical Laboratory
CMI
INRiM Istituto Nazionale di Ricerca Metrologica
LNE Le progrès, une passion à partager
MIKES Centre for metrology and accreditation
l'Observatoire de Paris SYRTE Systèmes de Référence Temps-Espace
PTB
Leibniz Universität Hannover
cnrs dépasser les frontières
UPMC Sorbonne Universités