International timescales with optical clocks (ITOC)


**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.
- The PTB transportable Sr lattice clock from PTB
- Transportable strontium lattice clock from PTB
- Transportable ytterbium lattice clock
- Laser frequency comparison
- 1.5 mW transfer laser
- 50 km optical fibre link
- Height difference ~ 1000 m

**Targets**:
- Clock accuracy 5 x 10^{-17}
- Clock instability 1 x 10^{-15} t^{-1/2}
- Optical link instability 10^{-14} t^{-1}

→ resolution of tens of cm in a few hours