TC-TF Report

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Madrid and Tres Cantos, Spain
15 – 18 May 2017

Time and Frequency

Agenda

- TCTF - 2017 Meeting
- EURAMET Comparisons (Time Interval and GNSS)
- EMPIR Projects ($1x10^{-18}$ Clock and OFTEN -$1x10^{-19}$)
- Financial sector regulation in Europe

Time and Frequency

TC-TF Meeting

EURAMET TC-TF 2016 Meeting was at ROA on March

Main Subjects:

- EURAMET TF projects
- EMRP-EMPIR projects
- BIPM Contribution (UTC, CCTF, Key Comparison)

STRATEGY

The development of accurate ground atomic clocks

Target accuracy: 10^{-17} - 10^{-18}

Space applications of atomic clocks and time-frequency metrology

Target accuracy: 10^{-16} - 10^{-17}

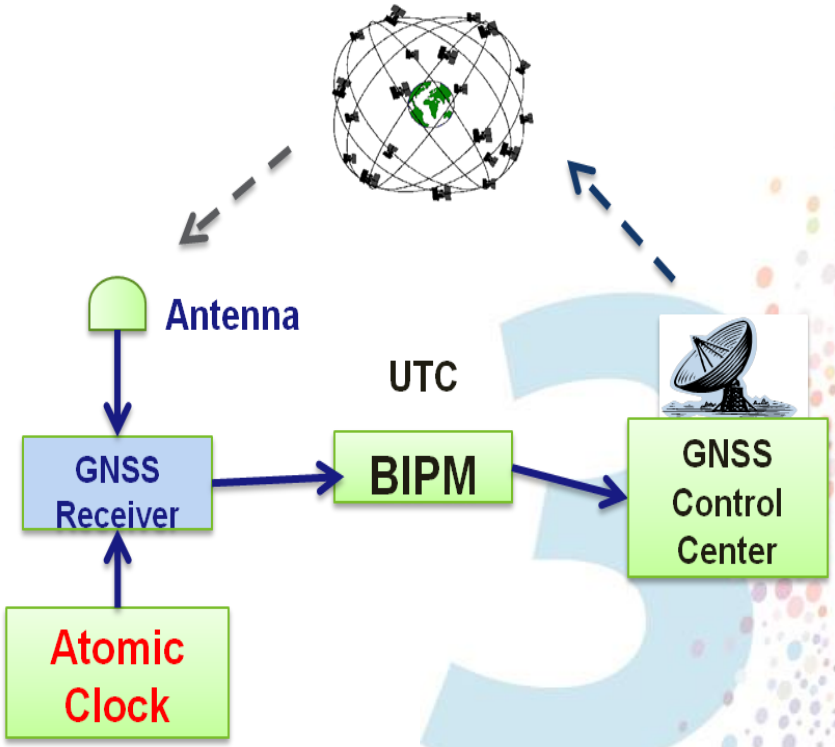
Time and frequency dissemination and comparison

In ground <10^{-18} and <0.1ns; In Space <10^{-16} and <0.1ns

Accurate time scale generation and traceability (from 7 ns to <2 ns)

Impacts: New second, Gravity wave detection, fundamental constant, gas detection, Space, Navigation, Communication

Time scale generation with low uncertainty



Atomic Clocks Accuracy
10^{-14} - 10^{-16}

Time deviation
$\Delta t / t = \Delta f / f =$ 1 – 0.01 ns/day

Time scale generation depends
- Delay on antenna
- Delay on Cables
- Delay on GNSS receivers

Time Scale Shift
UTC- UTC(k) : **5 -100 ns**

EMPIR Projects:
OC-18
OFTEN

EURAMET Projects:
GNSS Receiver Comparisons
Time Interval and Cable Delay Measurements

Time Interval Comparison

Comparison of time interval measurement with high speed oscilloscopes (Project 1288) **Pilot Study completed**

Participants :

AGH and NIT (Poland), SIQ (Slowenia), UME (Turkey), SASO (SA)

- **3 ps expanded uncertainty of the travelling standard**

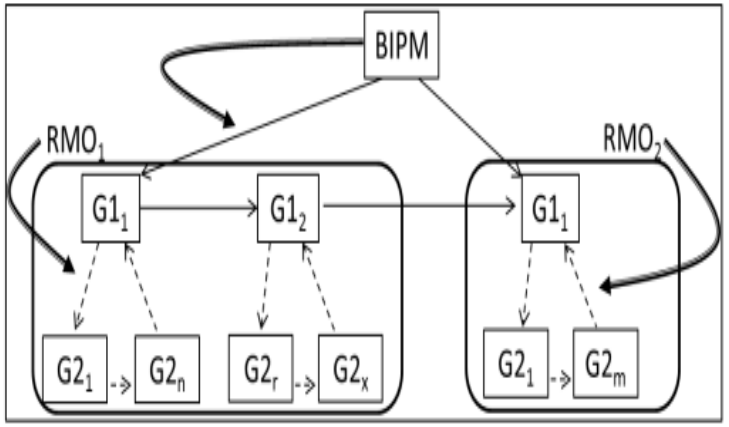
-Measurements with osilascope agree within a few ps

-Measurement with Counter very surprising >100 ps

New Time Interval generators are stable enough (<3 ps) to be travelling standards for new Time Interval Supplementary Comparison in 2017

GNSS Receiver Comparison

- **BIPM** prepared **Guidelines for** GNSS receiver calibration for UTC time comparisons



- Uncalibrated GNSS receiver

  u_B uncertainty ≈ 20 ns

- Most TF labs contributing to UTC used manufacture calibrated GNSS receiver

  u_B uncertainty ≈7 ns

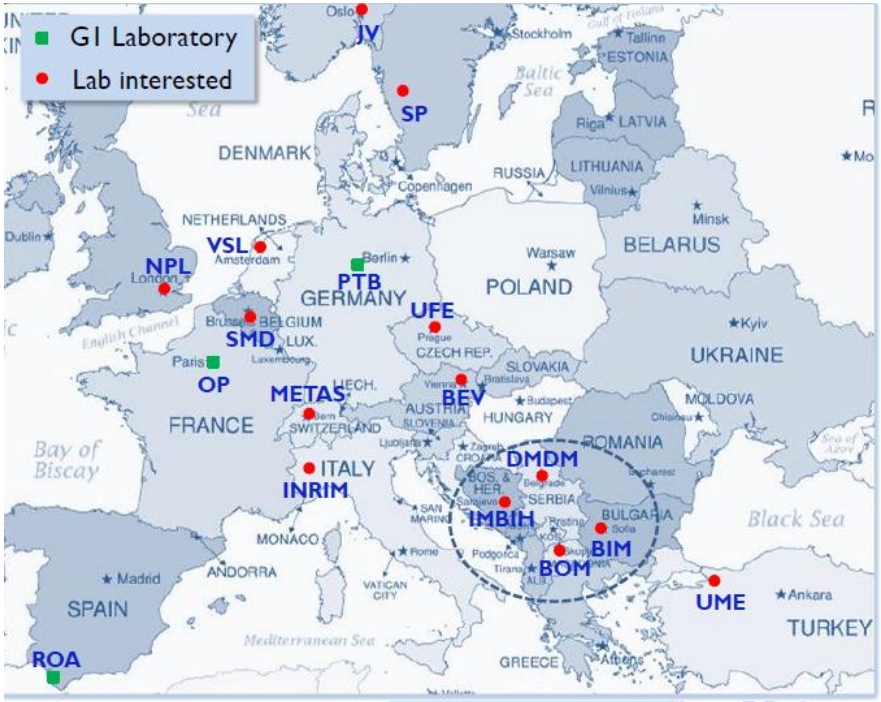
- Calibrated GNSS receiver used in UTC time scale evaluation

  u_B, targeting at 2-3 ns

Table 3: List of Group 1 laboratories (as of April 2015)

EURAMET	SIM	APMP	COOMET	AFRIMETS	GULFMET
OP	NIST	NICT	SU		
PTB	USNO	NIM			
ROA		TL			

GNSS Comparison



Project 1156, GPS link calibrations in support of CCTF-K001.UTC

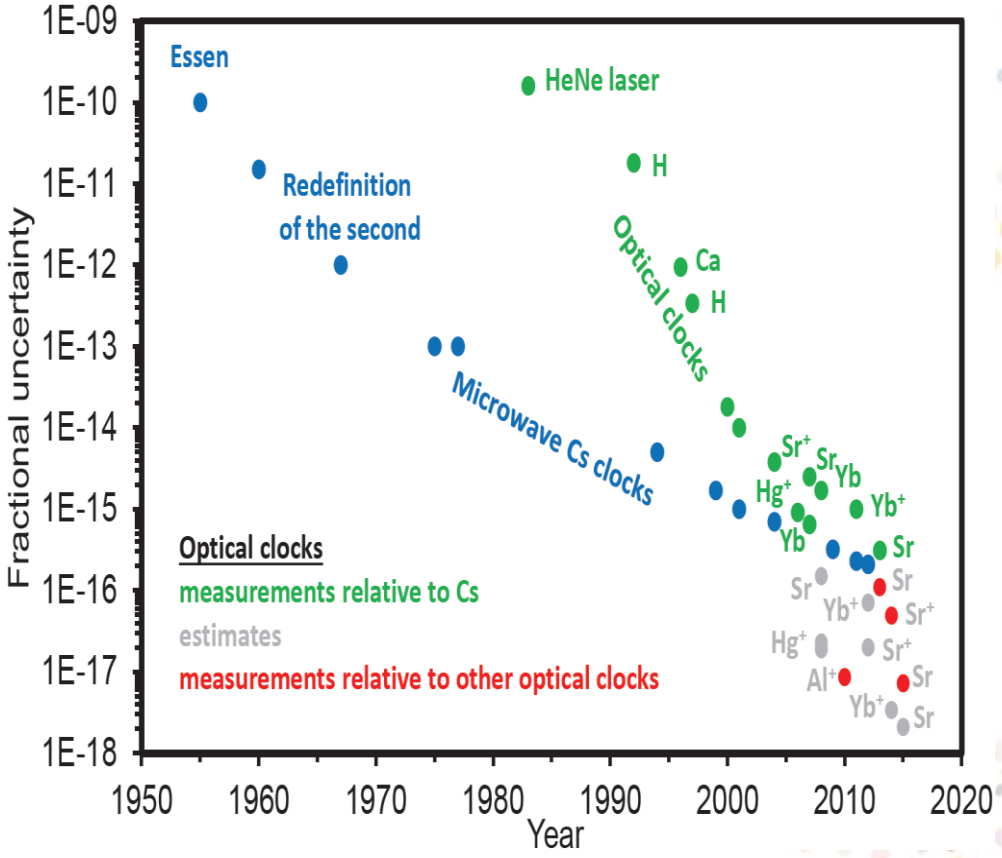
G1 Laboratories:
PTB, ROA, OP,

G1 – G2 Comparison organised by PTB:
G2: VSL, METAS, DLR, BEV

G1 – G2 Comparison organised by ROA:
G2: UME, BIM, BOM, IMBH, INRIM

u_B, from to 7 ns to 2-3 ns

Evaluation of atomic clocks and future optical redefinition of the second



Motivation for better optical clocks:

SI second currently defined using Cs, with the best realisations having accuracies of $1 - 2 \times 10^{-16}$

Optical clocks have already surpassed this performance and, with improvements to short-term stability, 10^{-18} should be attainable *within a workable measurement time*

Impacts: New second, Gravity wave detection, fundamental constant, gas detection, Space, Navigation, Communication

15SIB03, Optical Clocks with 1E-18 uncertainty

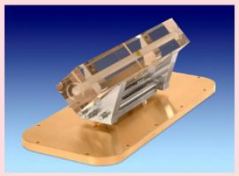
Aim: Development world-leading optical clocks with target accuracy: 1E-18

Reduce statistical uncertainty
by achieving coherent interaction times > 1s between atoms and probe light
Target: $1 \times 10^{-16}/\sqrt{\tau}$

Verify total uncertainty
Target: 1×10^{-18} after just a few hours

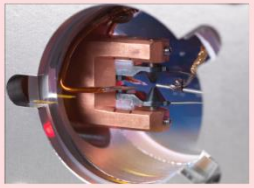
Reduce systematic uncertainty
through improved understanding and control of dominant frequency shifts
Target: 1×10^{-18}

WP1: Stable lasers and stability transfer



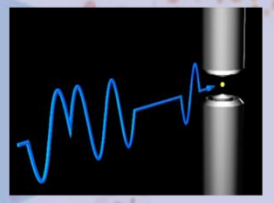
- Improve laser stability at atoms by one order of magnitude
- ULE and cryogenic silicon cavities / spectral hole burning / active resonators / femtosecond combs

WP2: Probing trapped atoms with sub-Hz resolution

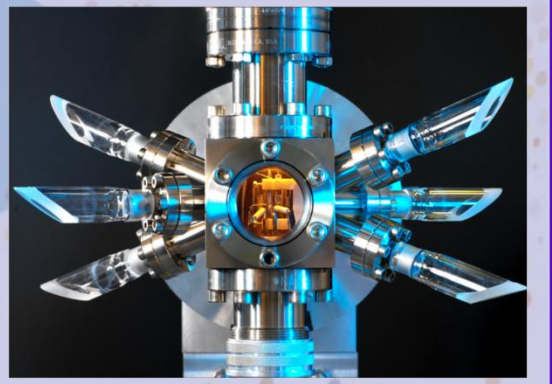


- Improve atomic coherence by one order of magnitude
- Ion trap materials & geometry / lattice trap depths / theory / collisions & scattering

WP4: Advanced clock operation



- Novel interrogation schemes such as hyper- Ramsey / zero dead-time probing
- Direct comparisons of local clocks to verify performance



WP3: Evaluation of systematic uncertainties

- Control frequency shifts from blackbody radiation and lattice traps
- Vacuum chamber design / thermometry / modelling / hyperpolarisability / collisions

WP5: Creating impact

Knowledge transfer: Publications in peer-review journals / conference presentations / website / specifications documents

Stakeholder engagement: Standards and technical committees / commercialisation of subsystems

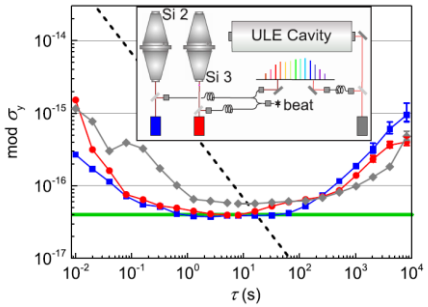
Training: Summer school for PhD students / lectures in university courses / secondments

NMI Partners: NPL, PTB, INRIM, LNE, OBSPARIS, TUBITAK UME, VTT
Industrial Partners: LUH, UCPH, UMK

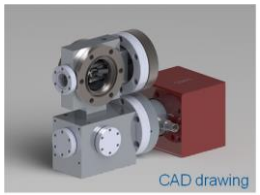
Optical Clocks with 1E-18 uncertainty

Progress highlights:

PTB have demonstrated laser instabilities 2x better than previous state-of-the-art, reaching 4 $\times 10^{-17}$ at 1-10 s.
Lasers locked to single-crystal Si cavities at 124K

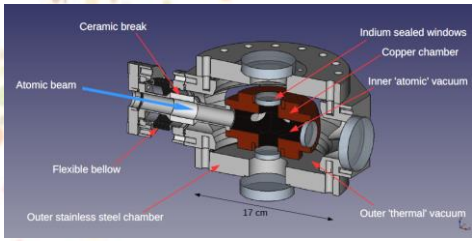


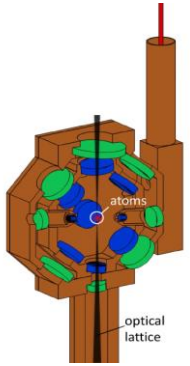
NPL designing new single-ion traps, targeting low motional heating rates of the ion to enable long coherent probe times.



1×10^{-18}, need excellent control of temperature, geometry and material properties,
INRIM designing room temperature system for Yb,
PTB designing cryogenic system for Sr.

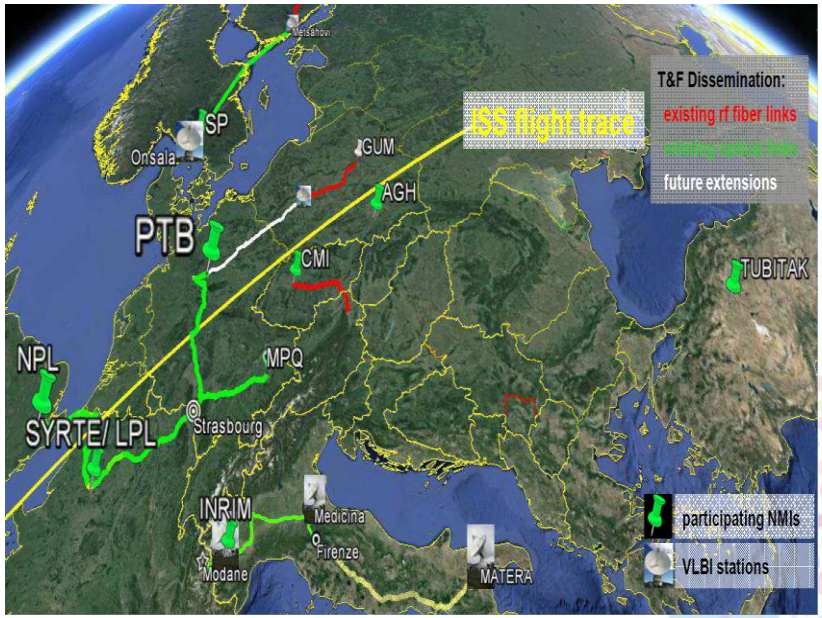
Sr^+	Yb	Sr
298 K ± 200 mK	298 K ± 30 mK	298 K ± 10 mK 77 K ± 1000 mK





TÜBİTAK UME developed new Yb fs Comb,
700 – 1400 nm, 36 fs, 45 dB fceo beat signal.

15SIB05, Optical Frequency Transfer – a European Network (OFTEN)



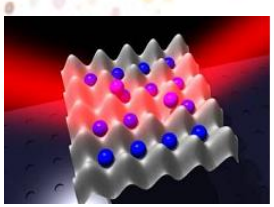
WP2
Assesment of ultimate limits of Fiber frequency transfer;
Develop software &hardware for autonomous & reliable operation

WP1
Comparison of optical clocks at SYRTE, NPL, and PTB via **joint fibre link** at 10^{-17} unc.

inputs for coordinated

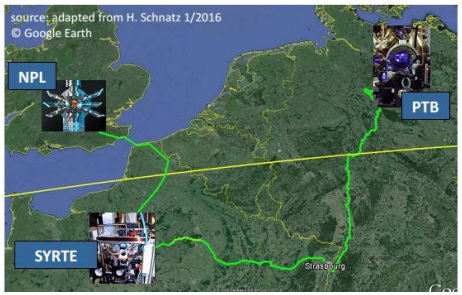
WP3
Fast, accurate, on demand comparisons of Cs fountains at a level only limited by clocks

WP4
Addressing stakeholder community:
Frequency dissemination to non NMIs such as spectroscopy, geodesy, VLBI, academia



Optical Frequency Transfer – a European Network (OFTEN)

Progress highlights:



For comparison of SYRTE – NPL - PTB comparison via fiber at 1 $\times 10^{-17}$ uncertainty :
Sub- links maintained and nose characterization < 1 $\times 10^{-18}$ is started
First optical clocks comparison performed between NPL and SYRTE

Evaluation study related Cs fountain comparison at 1 $\times 10^{-16}$ between PTB - GUM

Frequency dissemination via fiber for non NMI users and spectroscopy users:
100 MHz, 10 MHz and 1PPS dissemination,
Methonol spectroscopy 10.3 mm, Yb spectroscopy at 578 nm.

Finance Regulations in USA and EU

- FINRA OATS 7430
  Financial Industry Regulatory Authority
  Rule 7430: Specifies 1 s to NIST clock

SEC 613, Securities and Exchange Commission
  Rule 613: 50 ms to NIST clock

- **ESMA MiFID II RTS 25**
- European Securities and Markets Authority
  Regulatory Technical Standard RTS 25 deals with clock synchronisation to UTC < 0,1 ms

  – **Will come into effect on 3 January 2018**
  - **Transpose into national laws of member states by 3 July 2017**

Financial sector regulation in Europe

- NMI Workshop hosted by NPL, Jan 2017
  - Aim to encourage NMIs to engage with their national finance sectors
  - 11 NMIs represented
- National finance sector workshops
  - London: May 2016, Feb 2017

Time Traceability for the European Finance Sector

A one-day workshop for NMIs on the requirements for compliance with the new MiFID II regulations

DATE: **18 JANUARY 2017**
TIME: **10:00 – 16:00**
VENUE: **NPL TEDDINGTON**

- Timestamps should be based on UTC using UTC(*k*)
- Requires demonstrated traceability to UTC by documenting system design & functioning
- EURAMET and WELMEC cooperation very important for European LEGISLATION for LEGAL TIME

Thank you

for your attention

Time and Frequency