UTC(OP) Time Scale and French Legal Time

Michel ABGRALL, on behalf REFMET Group/Références Nationales de Temps

AG FIRST-TF, October 1st 2026

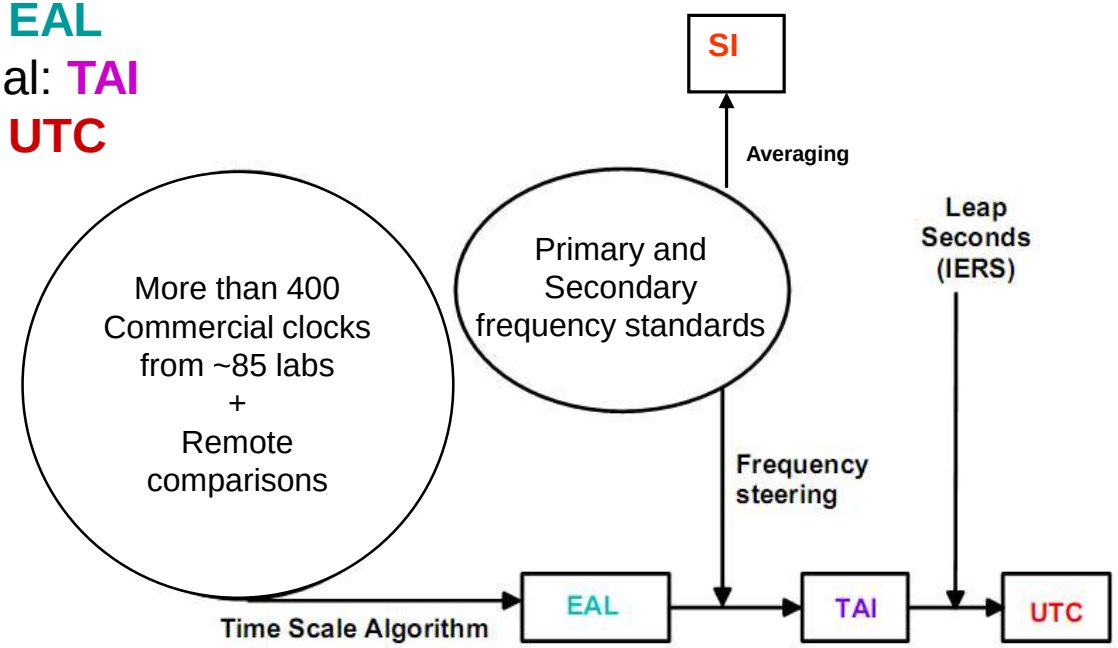
Outline

- UTC, TAI, SI
- LNE-OP clock ensemble
- Atomic fountains
- UTC(OP) redundant Timescale
- Satellite time transfer techniques
- UTC(OP) and Legal time dissemination

UTC, TAI, SI calculated by the BIPM

The BIPM produce each month

- The free running timescale: **EAL**
- Temps atomique international: **TAI**
- Universal coordinated time: **UTC**
- The **SI** Second



- The SI Second : an averaging of PSFS data provided by a few NMI
- UTC maintained close to UT1: |UTC – UT1| < 0,9 s (leap seconds*)

  UTC – TAI = - 37 s since January 1st 2017
- UTC: « paper » timescale calculated for the previous month
- NMI produce predictions of UTC: UTC(k)
- **UTC – UTC(k)** published in the **Circular T**

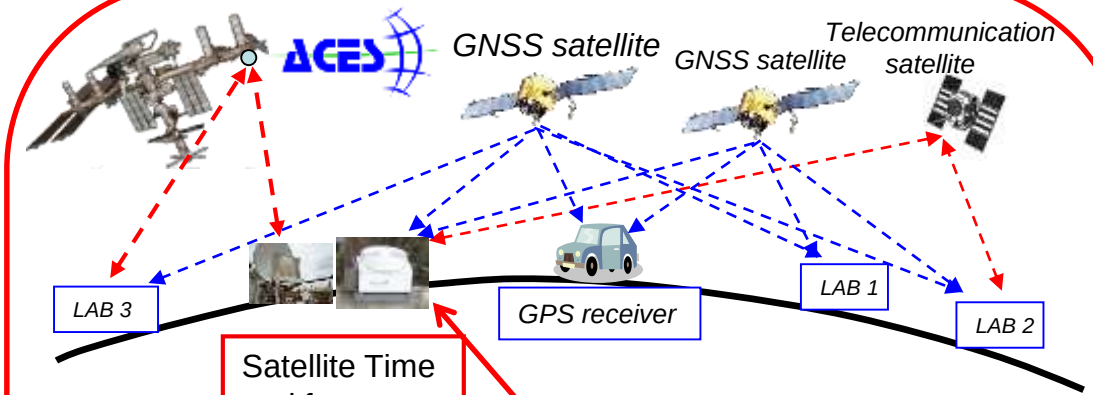
* Draft resolution C on continuous UTC for the 28th CGPM (Oct 2026)

➢ Enlarge the tolerance on |UT1 - UTC| to 3600 s, proposed date 20 May 2027

LNE-OP atomic clock ensemble

REFMET

FOP



Satellite Time and frequency transfer

GNSS and TWSTFT ACES ground terminal

BIPM other NMIs and labs

UTC(OP)

Timescale generation



Cs beam

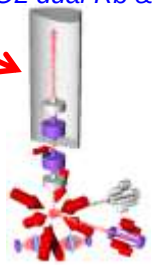
H-maser

Cryogenic sapphire Osc.



stabilized fiber links

FO2 dual Rb & Cs



FO1 Cs fountain



FOM transportable Cs

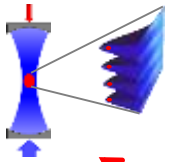


LTE ultra-stable reference & atomic fountains

Hg optical lattice clock



Sr optical lattice clock

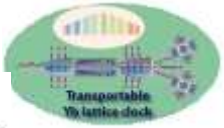


Sr optical lattice clock





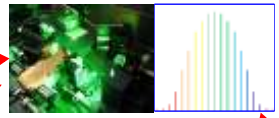
1062 nm ultra stable laser



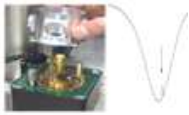
Yb Transportable optical lattice clock



689 nm ultra-stable laser



Optical frequency combs



Laser stabilization using spectral hole burning



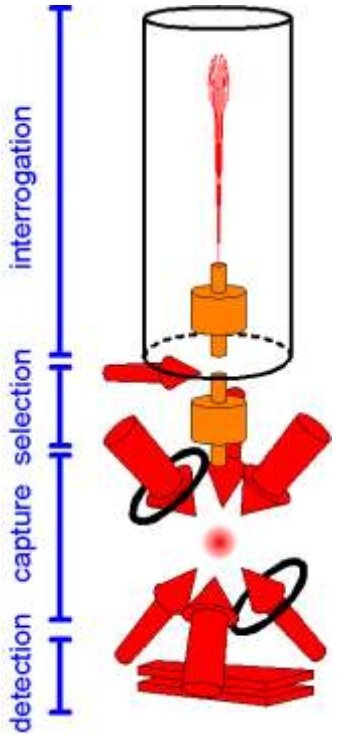
1.5 µm ultra-stable laser

White Rabbit



T-REFIMEVE fiber network: national research infrastructure (LTE&LPL)

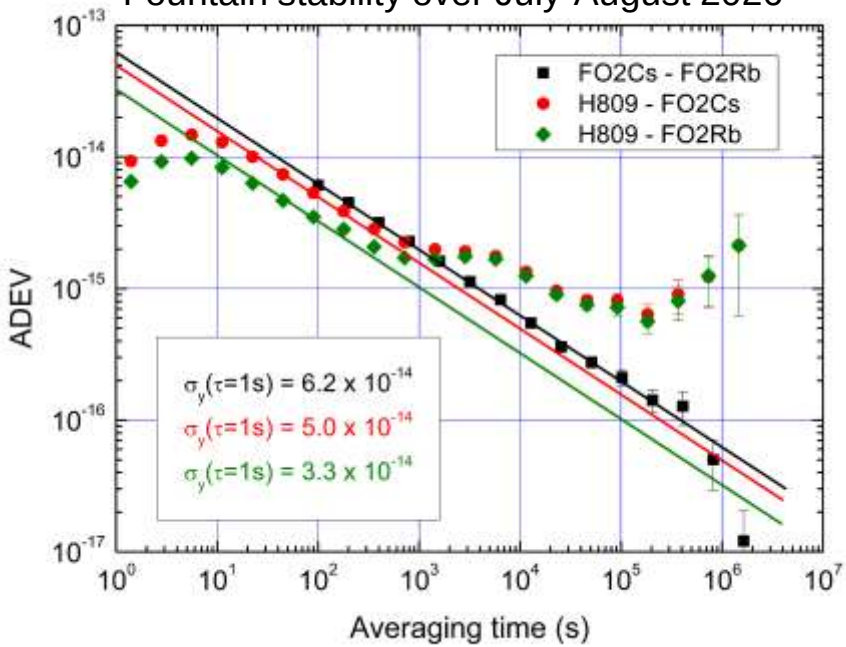
Atomic fountain clocks



Fountain typical accuracy

FO1	3.5×10^{-16}
FO2-Cs	2.1×10^{-16}
FO2-Rb	2.4×10^{-16}

Fountain stability over July-August 2026



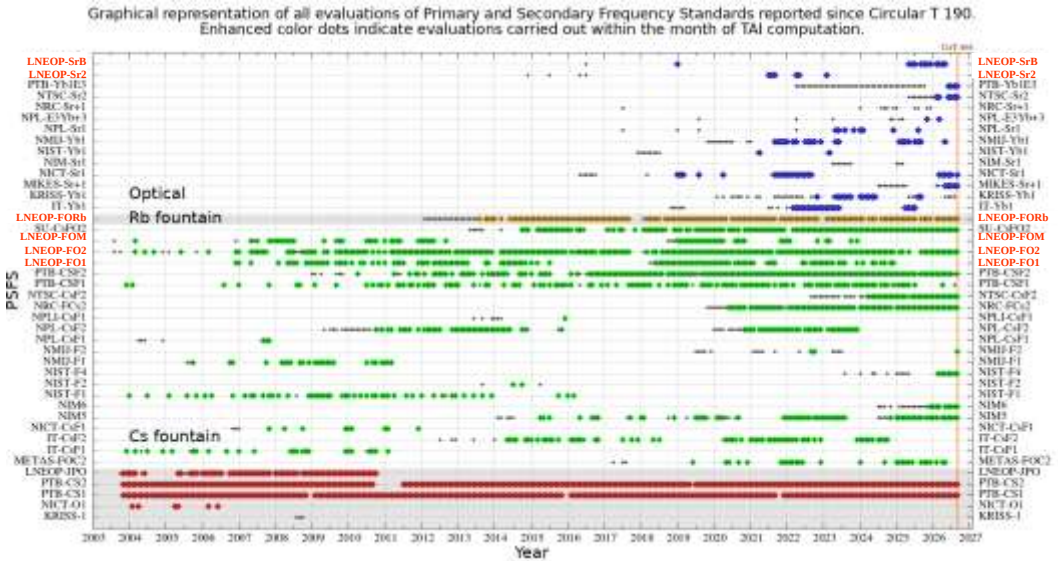
- Calibration of TAI by LNE-OP fountains

One report corresponds typically to a quasi continuous measurement of a H-maser frequency for 20 to 30 days

u_B ~ 2-4 x 10^{-16} u_A ~ 1-2 x 10^{-16}

$u_{link/maser}$ ~ 0.5-2 x 10^{-16}

- About 20-30 % of the calibration reports sent to the BIPM worldwide were provided by the LNE-OP fountains over the past years

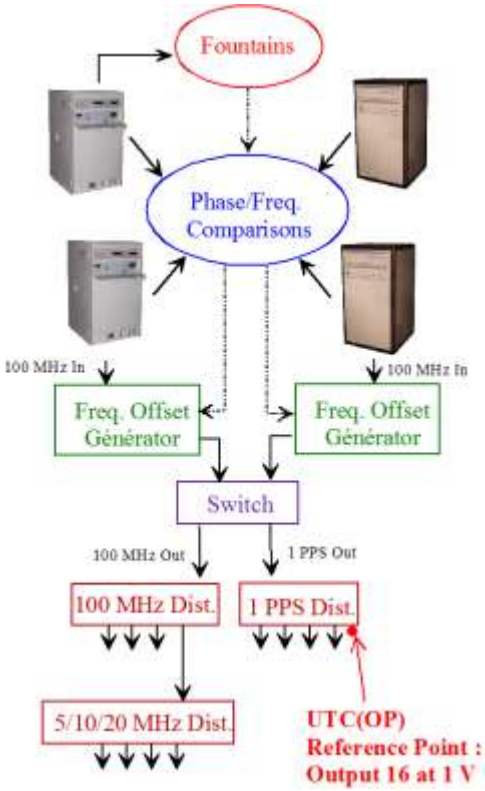


Realization of the French Timescale UTC(OP)

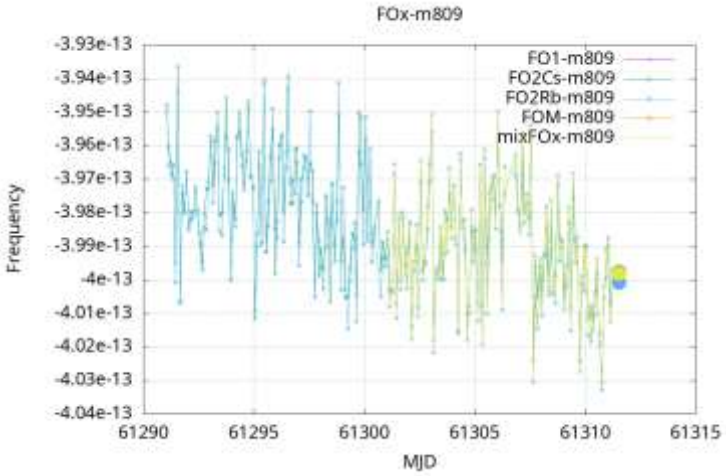
Steering algorithm combining the operation continuity of commercial clocks (H-masers) and the stability and accuracy of atomic fountains to limit the phase cumulation between 2 release of Circular T (30-40 d)

- Automatic data processing for fountain monitoring (hourly) providing daily frequency calibrations of our 5 H-Masers by the fountains at the low 10^{-15} level
- Daily main steering using a linear fit of the fountain calibrations over the past 10 days updated automatically
- Additional steering of a few 10^{-16} towards UTC updated monthly using the last available *Circular T* compensating for:
  - The slope of UTC(OP) – UTC
  - Half of the phase difference over the following month

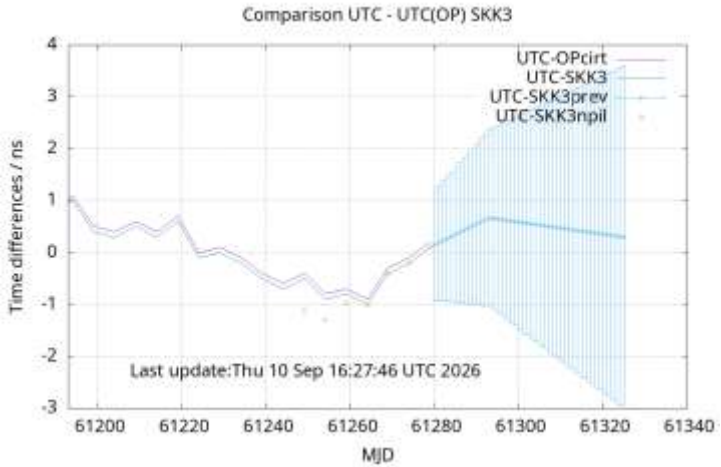
Redundant Timescale



H-Maser prediction

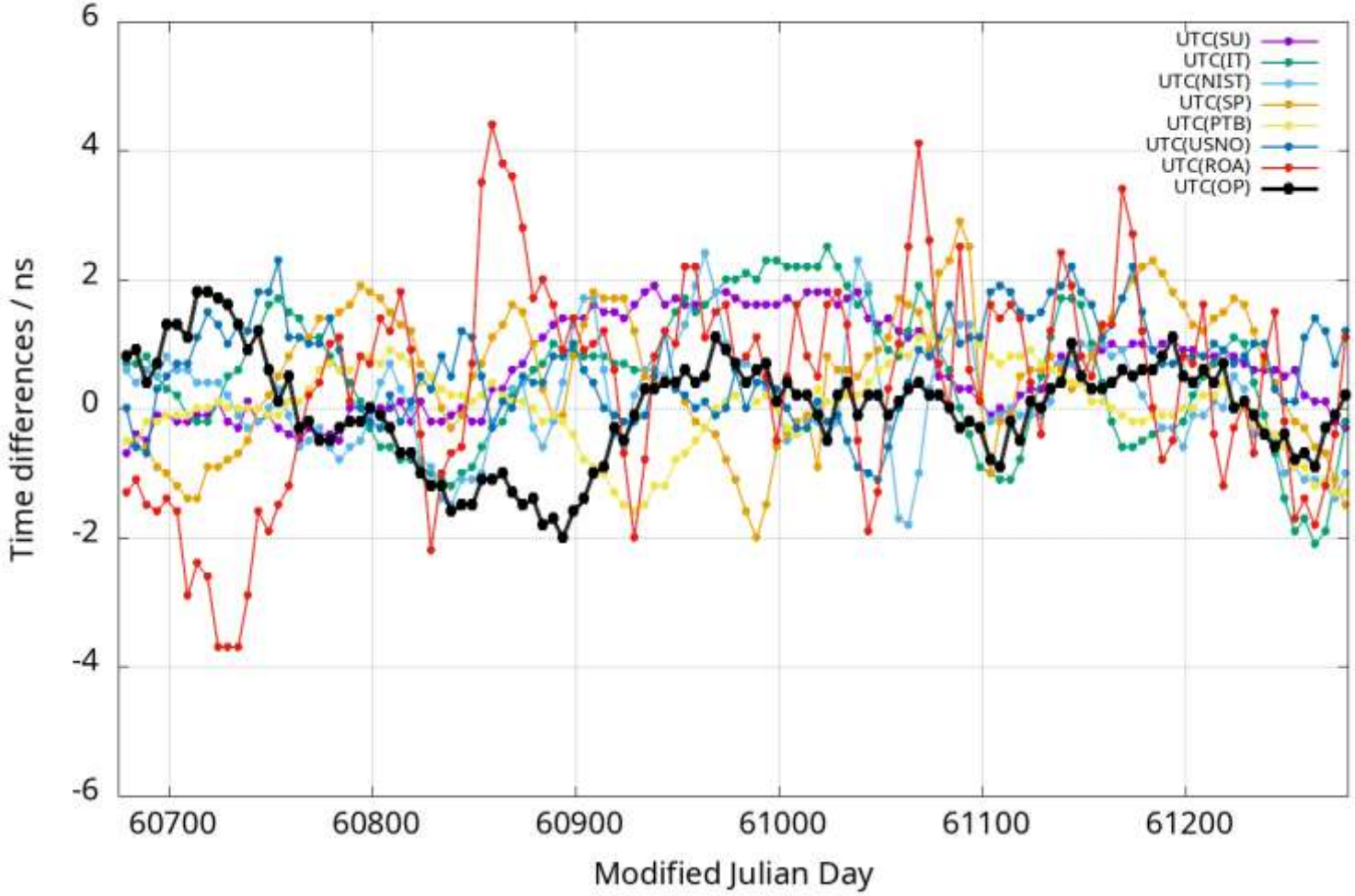


Monthly steering and prediction



UTC(OP) Performances

Comparison of a few UTC(k) to UTC since beginning of 2025



- UTC(OP) is one of the best real time realizations of UTC
- Departure of a few ns
- Approaching the uncertainty of the time transfer links
- 3 x 10^{-16} frequency offset corresponds to 1 ns cumulated phase over 40 *d*

Satellite Time Transfer Techniques

Two Way Satellite Time and Frequency Transfer (TWSTFT)

- Satre Modems, Frequency up/down conversion to the Ku band, Geostationary satellite
- 2 stations (EU/USA, EU/ASIA + experiments)
- TWSDRR : Emission using Satre Modem, Reception using SDR
- TWSDRR traveling equipment for link calibration

✓ Accuracy 1-2 ns

➢ Developments: SRS (Japan) Emisson/reception SDR (with FEMTO-ST)

TWSTFT antennas at OP



GNSS (GPS/GALILEO/GLONASS/BEIDOU)

- About 10 receivers from different manufacturers (multi channels, multi frequency, multi GNSS)
- Traveling equipment for relative calibration (OP72/OP74)
- Group1 lab (OP, PTB, ROA, INRIM in EURAMET) for the relative calibration of GNSS stations of TAI labs

✓ Accuracy 1-3 ns

➢ Experiments on absolute calibration of GNSS receivers

➢ Advanced techniques such as iPPP with BIPM and CNES

➢ Comparisons using GALILEO signals, BEIDOU in near future

GNSS antennas at OP



▪ TWSDRR: main time transfer for TAI contributions

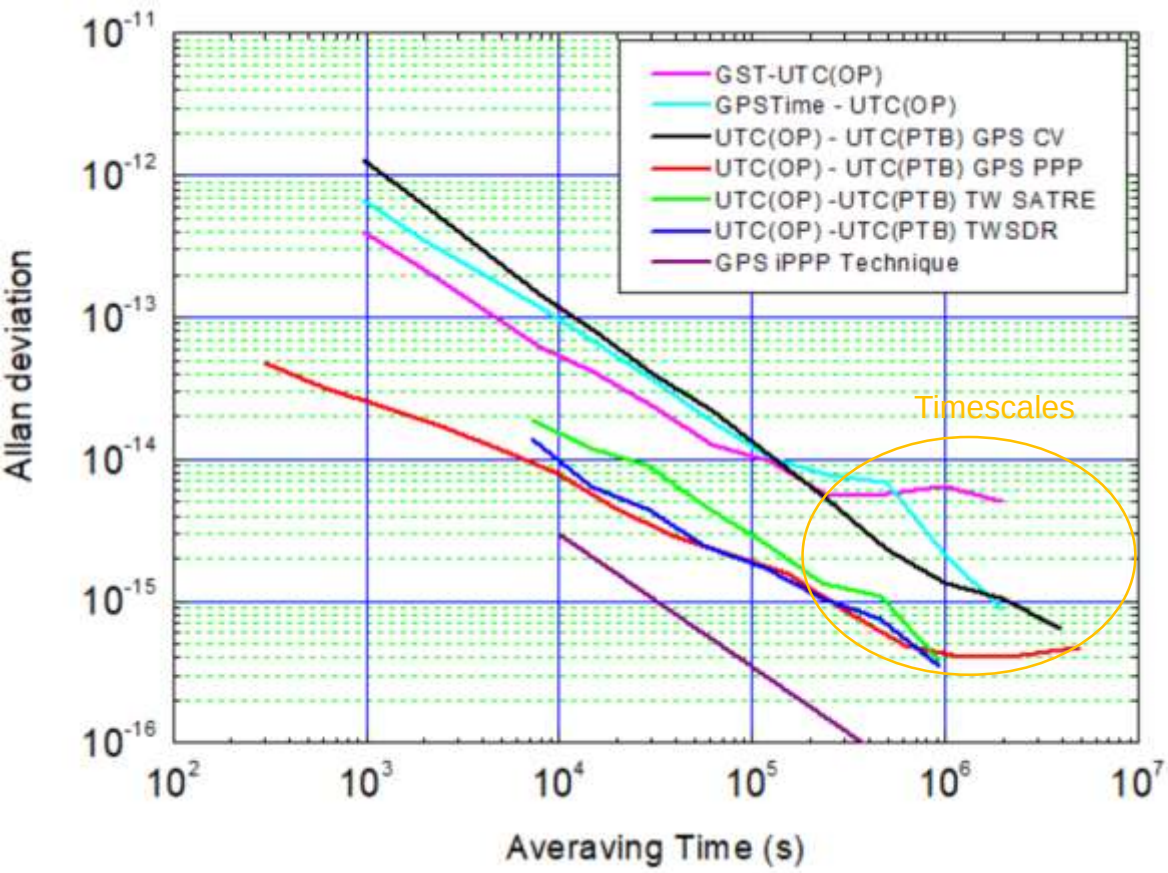
➢ TWSTFT/GPSPPP and GPS as backups

Multi-techniques comparisons: PPP, iPPP, TWCP, TWSDR, Fiber networks, ACES MWL/ELT

Contributions to GALILEO:

- UTC(OP) included in the steering of GST (OP, PTB, ROA, RISE, INRIM): time transfer data provided daily
- Relative calibration of GPS stations of the PTFs and of the participating labs

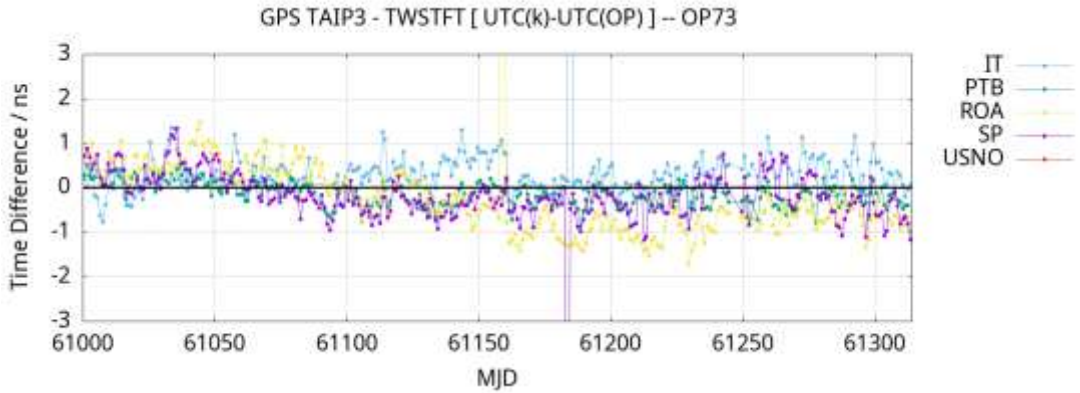
Satellite Time transfer performances



Accuracy TW ~1 ns
Accuracy GNSS ~1.5 - 3 ns

GPS carrier/phase techniques require IGS products that are available with some latency

Example of satellite link closure



Dissemination of UTC(OP)

EGNOS: European Geostationary Navigation Overlay System

- Plane navigation
- RIMS-PAR connected to UTC(OP): ENT-UTC, ENT-UTC(OP) in real time
- Preparation for the implementation of EGNOS V3

GPS CV comparisons to 12 French laboratories

- Observatories: OCA, OB, ON
- National institutions: CNES, DGA (2 centers), the French navy
- Industry: Orange (3 centers), Spectracom/Orolia/Safran, Keysight Technologies

Time difference to UTC(OP) available daily (accuracy 2-10 ns)

GPS PPP using NRCAN software with OB, OCA, CNES (H-Masers)

SYREF System, operated by OB, referenced to UTC(OP) for frequency calibrations in ~10 other labs

Temps Atomique Français TA(F)

- « Paper » timescale TA(F) computed monthly from 20-30 industrial clocks (9 French labs)
- Weighted averaging of clock data based on ARIMA
- Frequency steering using fountain calibrations
- Collected clock (Cesiums and H-Masers) data also sent to the BIPM and included in EAL computation

➢ Ongoing study to include H-Masers in TA(F) computation

Dissemination of UTC(OP)

Web page https://heurelegalefrancaise.fr/

- As a replacement to the speaking clock (1933-2022)

Network Time Protocol (NTP)

- 2 Stratum 1 servers referenced to UTC(OP)
- Stratum 2 servers available to the public (~1E6 query/h)
- Uncertainty ~10 ms depending on the network characteristics
- Industrial contract SCPTime (Secure Certified Precise Time) with EASII IC

ALS162 Signal (162 kHz) Former name « France-Inter grandes ondes »

- Collaboration with ANFR, TDF, FH, LTFB, LTE
- Local commercial clocks connected via GPS CV to UTC(OP)
- ~500 kW emitter located in Allouis, in the center of France
- Accuracy : ~10^{-12} with the carrier; ~1 ms with the code representing French legal time

White rabbit

- In collaboration with FOP on the REFIMEVE Network
- Industrial contract Time As A Service with Safran

Bulletin H published monthly summarizing the main results

24h/24 & 7d/7 Operation of time activities, Quality management system (ISO 17025), Service Level Agreement, ZRR

Thank you !

M. Abgrall, J. Achkar, B. Chupin, O. Chiu, B. Fang, C. Lim, H. Le Goff, L. Lorini, F. Sparma, P. Tuckey