CCTF

23rd Meeting of the Directors of NMIs and Member State Representatives,
October 17-18, 2024

Towards a new definition for the second, a continuous UTC and a reference Lunar time

Noel Dimarcq *CCTF President*
Patrizia Tavella *CCTF Executive secretary*

Bureau International des Poids et Mesures

CCTF Strategy

- **CCTF nominal activities in Time and Frequency (TF) metrology:** definition and mise en pratique of the SI second, atomic frequency standards, time & frequency transfer techniques, establishment and diffusion of international atomic time scales, MRA and metrological traceability, …

- **Current priority topics (dedicated task force / task groups):**
  - Redefinition of the second
  - Continuous UTC
  - Lunar reference time

  → Envisaged CGPM 2026 resolutions

  - Traceability to UTC from GNSS measurements
  - Digitalization
  - Quantum technologies
  - Capacity building - Sharing resources to Improve the (Inter) National Timekeeping

Thanks to the actors and contributors

Great thanks to:

- **CCTF working groups / task groups for their strong involvement that maintains the momentum and ensures rapid progress in all CCTF topics**

- **BIPM Time Department for its outstanding support to CCTF activities**

- **NMIs / DIs for their strong support and their active contributions to BIPM and CCTF (and CCTF WG/TG) activities, including the sharing of resources for Capacity Building to improve the (Inter) National Timekeeping**

Sharing Resources for Capacity Building to Improve the (Inter) National Timekeeping

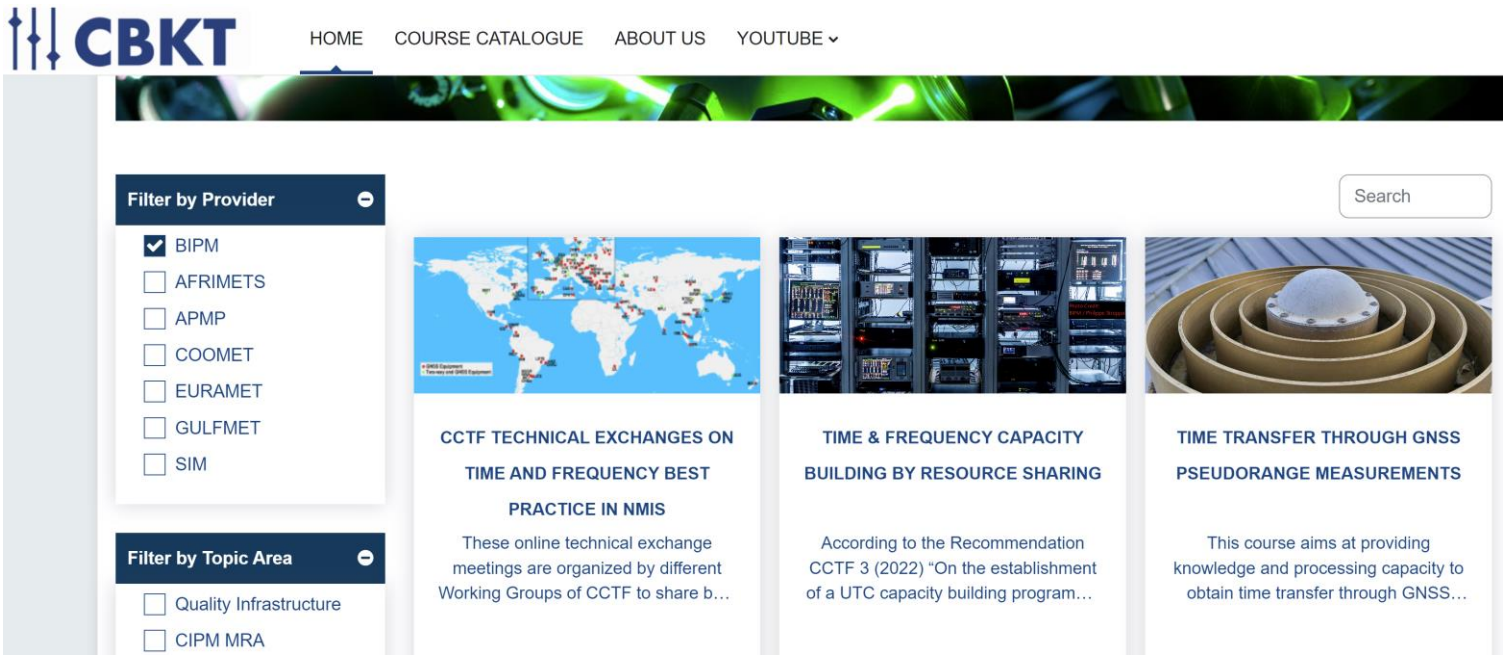
CCTF project (started on Oct 1st, 2023) on capacity building based on shared resources with:

- Dr Bharat Vattikonda, from NPL India (October 23 - September 24)
- Dr Yuko Hanado, formerly NICT Japan (in 2019 and April - July 24)
- Dr Tara Fortier, from NIST USA (September 24 - August 25)

Secondement sponsored by the IEEE society on Ultrasonic, Ferroelectric, and Frequency Control

→ **Putting in common the training tools**, videos, guidelines, software modules.. already available at the NMIs to increase the common heritage, with a coordination and global guidance by the BIPM.

→ **Organizing online or in presence training events** (APMP is organising a Time Scale Workshop next November in NPLI India; EURAMET a training school in October in ROA, Spain)



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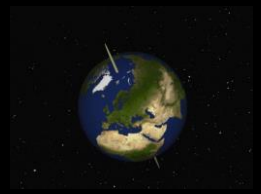
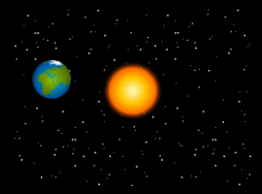
Please have a look and advertise proposed eLearning courses https://e-learning.bipm.org/

Redefinition of the SI second

Before 1967

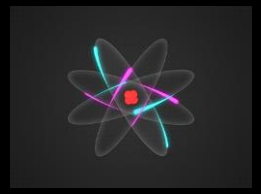
Duration of the solar day / tropical year





Since 1967

Resonance frequency of Cs atom



In 2030?

?

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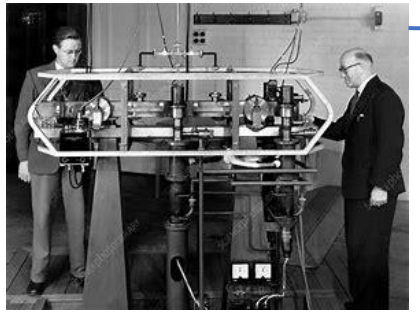
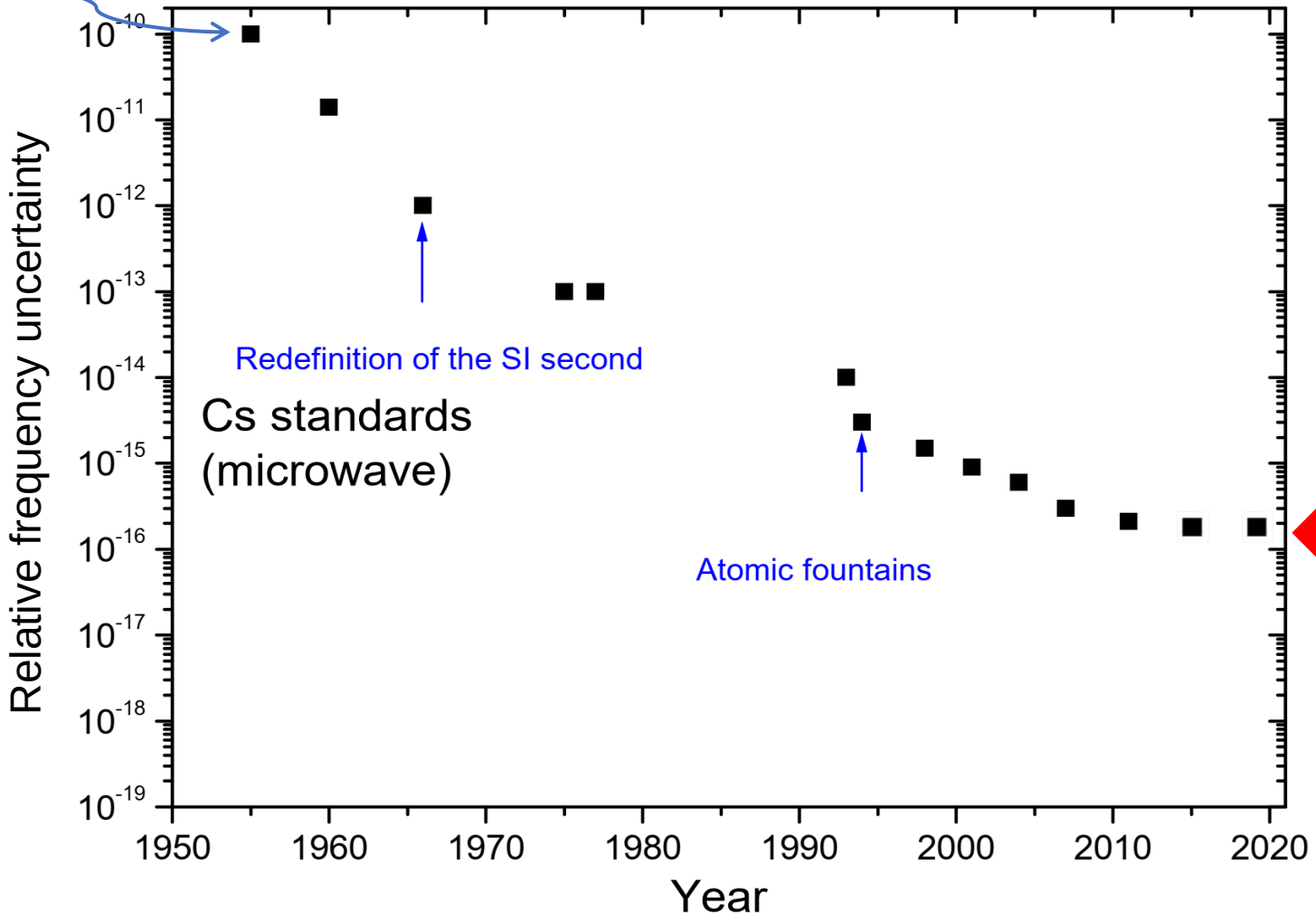
Realization of the SI second with primary Cs frequency standards

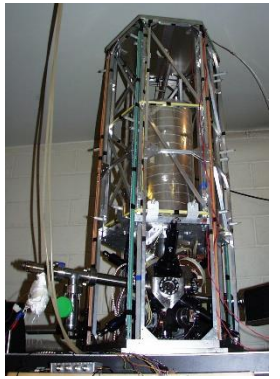


First Cs frequency standard (NPL)

Cs atomic beam frequency standard (PTB)



INRIM

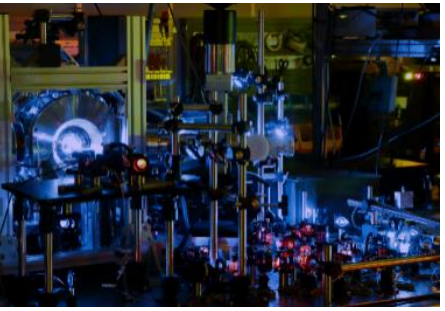


LNE-SYRTE

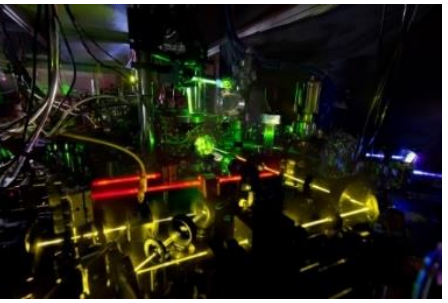
~ 11 Cs fountains in operation with best **accuracy ~ 10^{-16}**

NIM

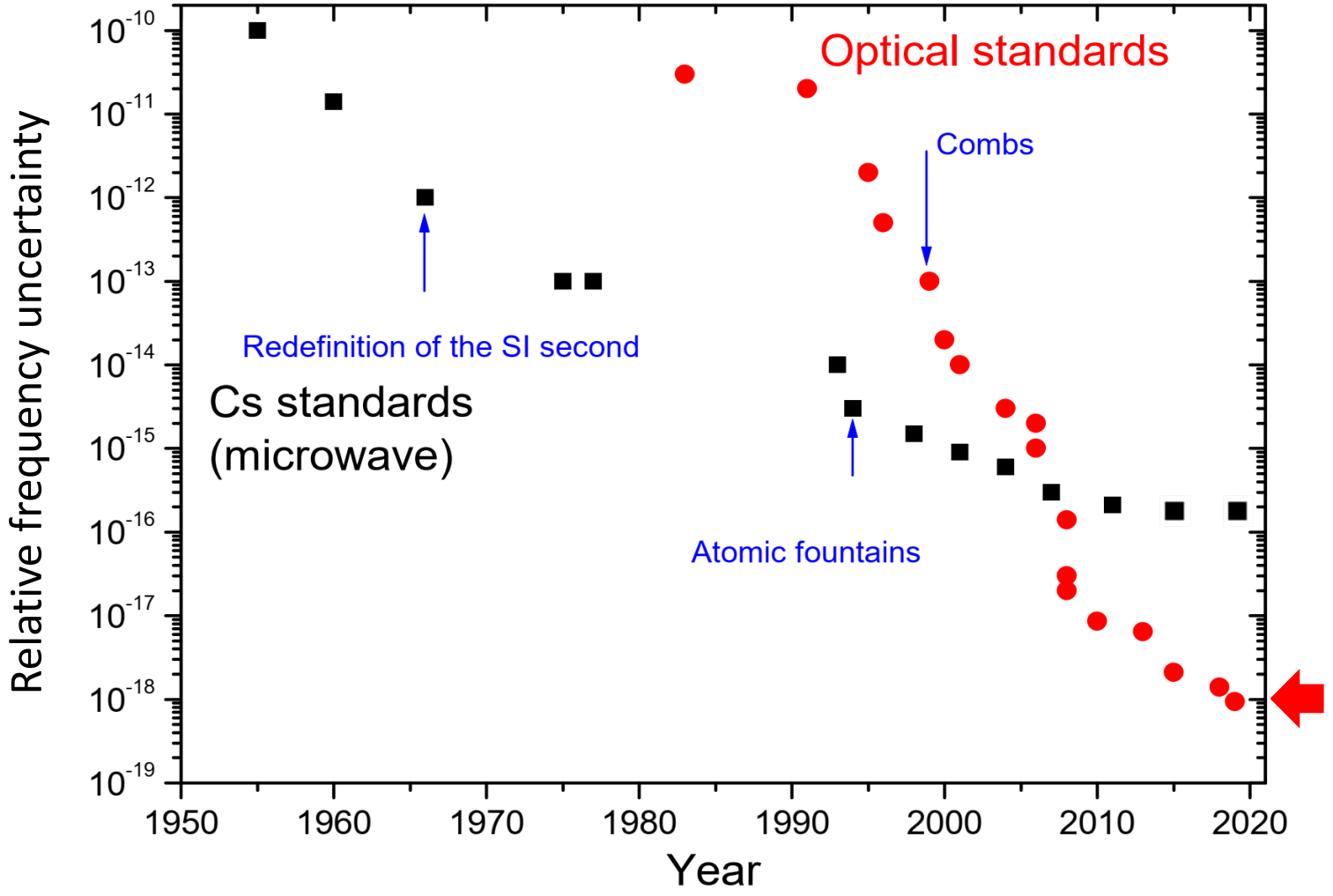
Accuracy obtainable by Cs clocks surpassed by Optical Frequency Standards



Sr lattice Clock (NICT)



Yb Lattice Clock (NIST)



> **40 OFS** in operation or under development in
> **18 institutes**
> **12 different species / transitions** (Sr, Yb, Hg, Yb+, Al+, Ca+, Sr+, …)
with best **uncertainty at 10^{-18} level**
(0.1 ps / day;
3 ns / 100 years)

CGPM 2022 Resolution 5 - On the future redefinition of the second

CGPM
General Conference on Weights and Measures
27th meeting - 15-18 November 2022

encourages the International Committee for Weights and Measures (CIPM)

- to promote the importance of achieving the objectives in the roadmap for the redefinition of the second,
- **to bring proposals to the 28th meeting of the CGPM (2026) for the choice of the preferred species, or ensemble of species for a new definition of the second, and for the further steps that must be taken for a new definition to be adopted at the 29th meeting of the CGPM (2030),**

and **invites** Member States to support research activities, and the development of national and international infrastructures, to allow progress towards the adoption of a new definition of the second.

Towards a redefinition of the second

CGPM 2022

Resolution 5 : ”bring proposals to the 28th meeting of the CGPM (2026) for the **choice of the preferred species, or ensemble of species** for a new definition of the second, and for the **further steps** that must be taken for a **new definition to be adopted at the 29th meeting of the CGPM (2030)**”

CGPM 2030

Redefinition of the second: Mandatory criteria fulfiled + Validation of the chosen option/species/transition(s)

Criteria / conditions to change definition

Mandatory criteria **To be achieved** before changing the definition

Achieved

- **Validation that Optical Frequency Standards (OFS) are at a level 100 times better than Cs**
- **Continuity with the definition based on Cs**
- **Regular contributions of OFS to UTC as secondary representations of the second**
- **Availability of sustainable techniques for OFS comparisons**
- **Knowledge of the local geopotential with a sufficient uncertainty level**
- **Definition allowing future more accurate realizations**
- **Access for National Metrology Inst. to primary or secondary realizations of the new definition**

Mandatory achievements frontier

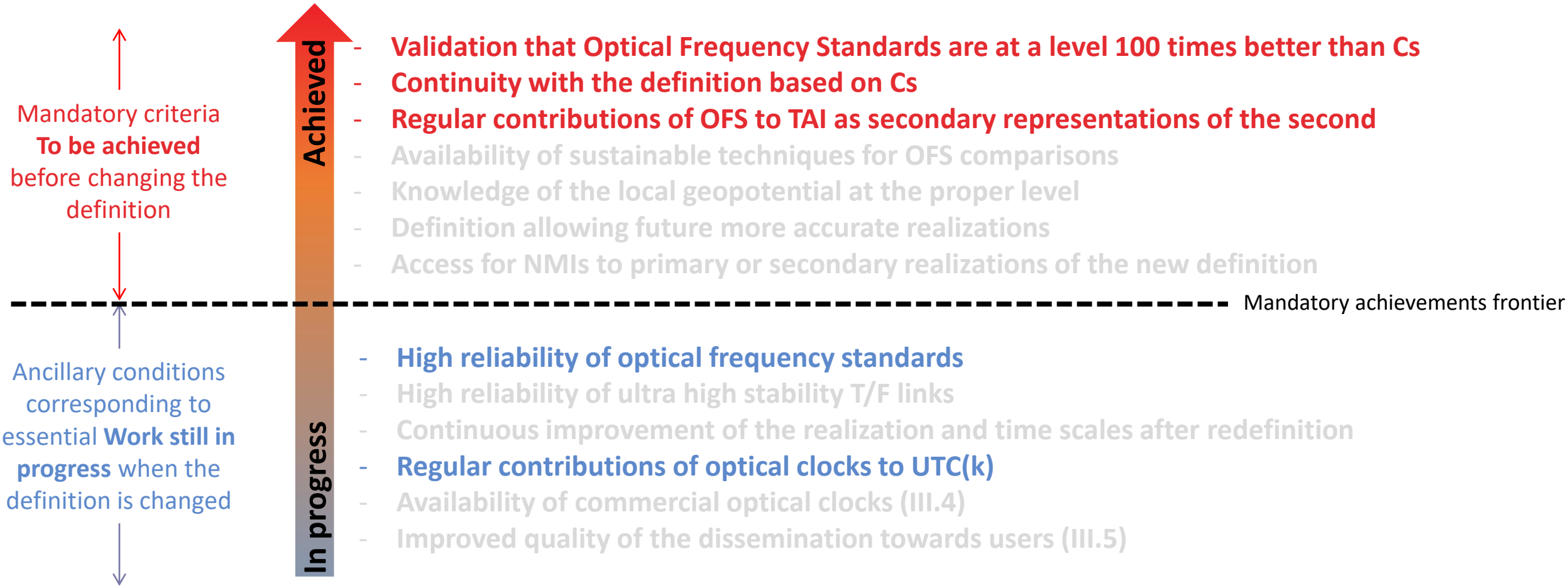
Ancillary conditions corresponding to essential **Work still in progress** when the definition is changed

In progress

- **High reliability of optical frequency standards**
- **High reliability of ultra high stability T/F links**
- **Continuous improvement of the realization and time scales after redefinition**
- **Regular contributions of optical clocks to UTC(k)**
- **Availability of commercial optical clocks**
- **Improved quality of the dissemination towards users**

Criteria / conditions to change definition

Frequency standards and contribution to atomic time scales



Criteria / conditions to change definition

TF comparison and dissemination

Mandatory criteria **To be achieved** before changing the definition

Achieved

- Validation that Optical Frequency Standards are at a level 100 times better than Cs
- Continuity with the definition based on Cs
- Regular contributions of OFS to TAI as secondary representations of the second
- **Availability of sustainable techniques for OFS comparisons**
- **Knowledge of the local geopotential at the proper level**
- Definition allowing future more accurate realizations
- Access for NMIs to primary or secondary realizations of the new definition

Mandatory achievements frontier

Ancillary conditions corresponding to essential **Work still in progress** when the definition is changed

In progress

- High reliability of optical frequency standards
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- Continuous improvement of the realization and time scales after redefinition
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Criteria / conditions to change definition

Acceptability of the new definition

Mandatory criteria **To be achieved** before changing the definition

Achieved

- Validation that Optical Frequency Standards are at a level 100 times better than Cs
- Continuity with the definition based on Cs
- Regular contributions of OFS to TAI as secondary representations of the second
- Availability of sustainable techniques for OFS comparisons
- Knowledge of the local geopotential at the proper level
- **Definition allowing future more accurate realizations**
- **Access for NMIs to primary or secondary realizations of the new definition**

Mandatory achievements frontier

Ancillary conditions corresponding to essential **Work still in progress** when the definition is changed

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- High reliability of optical frequency standards
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Fulfilment level of mandatory criteria

OFS = Optical Frequency Standard

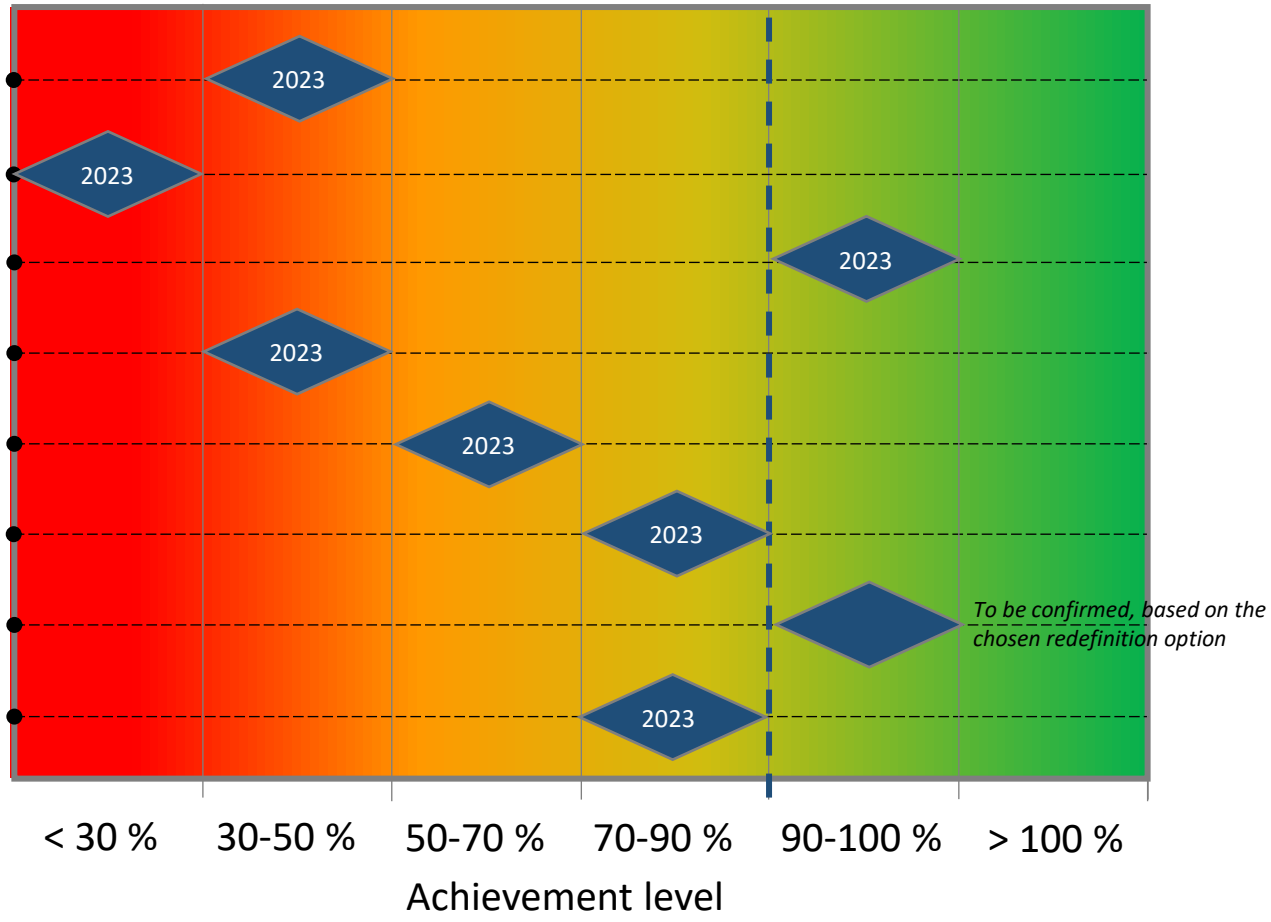
REQUIRED ACTIONS:

More OFS with accuracy in the 10^{-18} range

More comparison campaigns with fibre links or transportable clocks

Mandatory criteria

- I.1 - OFS accuracy budgets (< 2×10^{-18})
- I.2 - Validation of OFS accuracy budgets – Frequency ratios (< 5×10^{-18})
- I.3 - Continuity with the definition based on Cs (< 3×10^{-16})
- I.4 - Regular contributions of OFS to UTC (5 OFS contributing @ 2×10^{-16})
- II.1 - Availability of sustainable techniques for OFS comparisons (@ 5×10^{-18})
- II.2 - Knowledge of the local geopotential at the proper level
- III.1 - Definition allowing future more accurate realizations
- III.2 - Access to the realization of the new definition



→ **Will be updated for CCTF Nov. 2024**

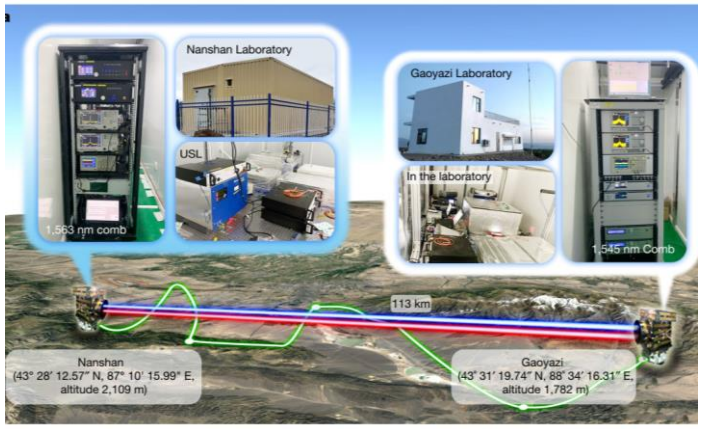
How to compare optical clocks at distance at 10^{-18} accuracy?

- **Techniques in the optical domain:**

Optical fibers
very promising, presently limited to continental links

Transportable optical clocks
some are available, other under further development

Optical comparison in space
at prove of concept level, quickly advancing



- **Several existing techniques operating in the microwave domain are possible candidates but only at the 10^{-17} uncertainty level at present time:**

GNSS Integer PPP, Satellite Two way Carrier Phase, microwave link of the ACES space mission, …

Fulfilment level of mandatory criteria

OFS = Optical Frequency Standard

REQUIRED ACTIONS:

More OFS with accuracy in the 10^{-18} range

More comparison campaigns with fibre links or transportable clocks

More OFS contributing regularly to TAI calibration

Mandatory criteria

- **I.1 - OFS accuracy budgets (< 2×10^{-18})**
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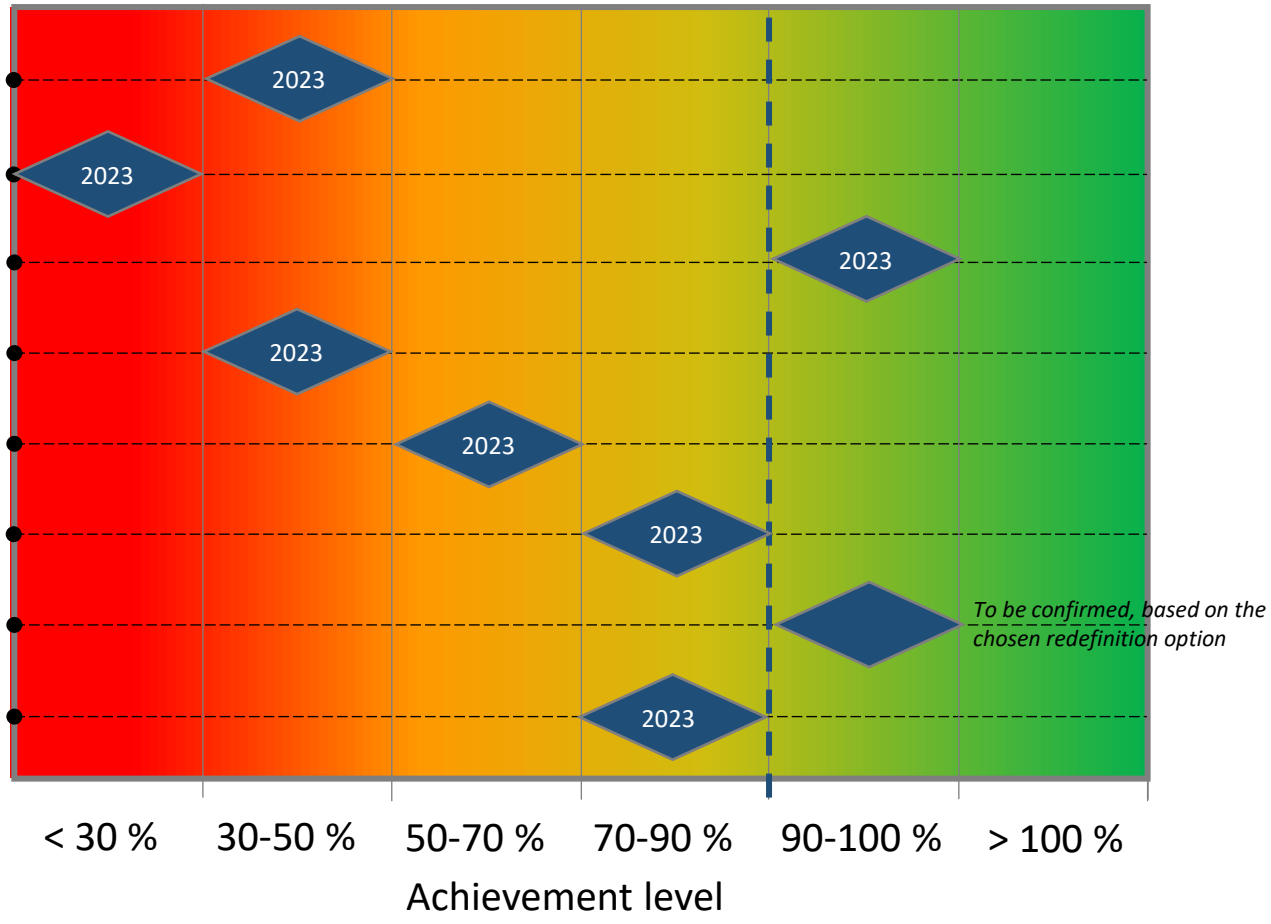
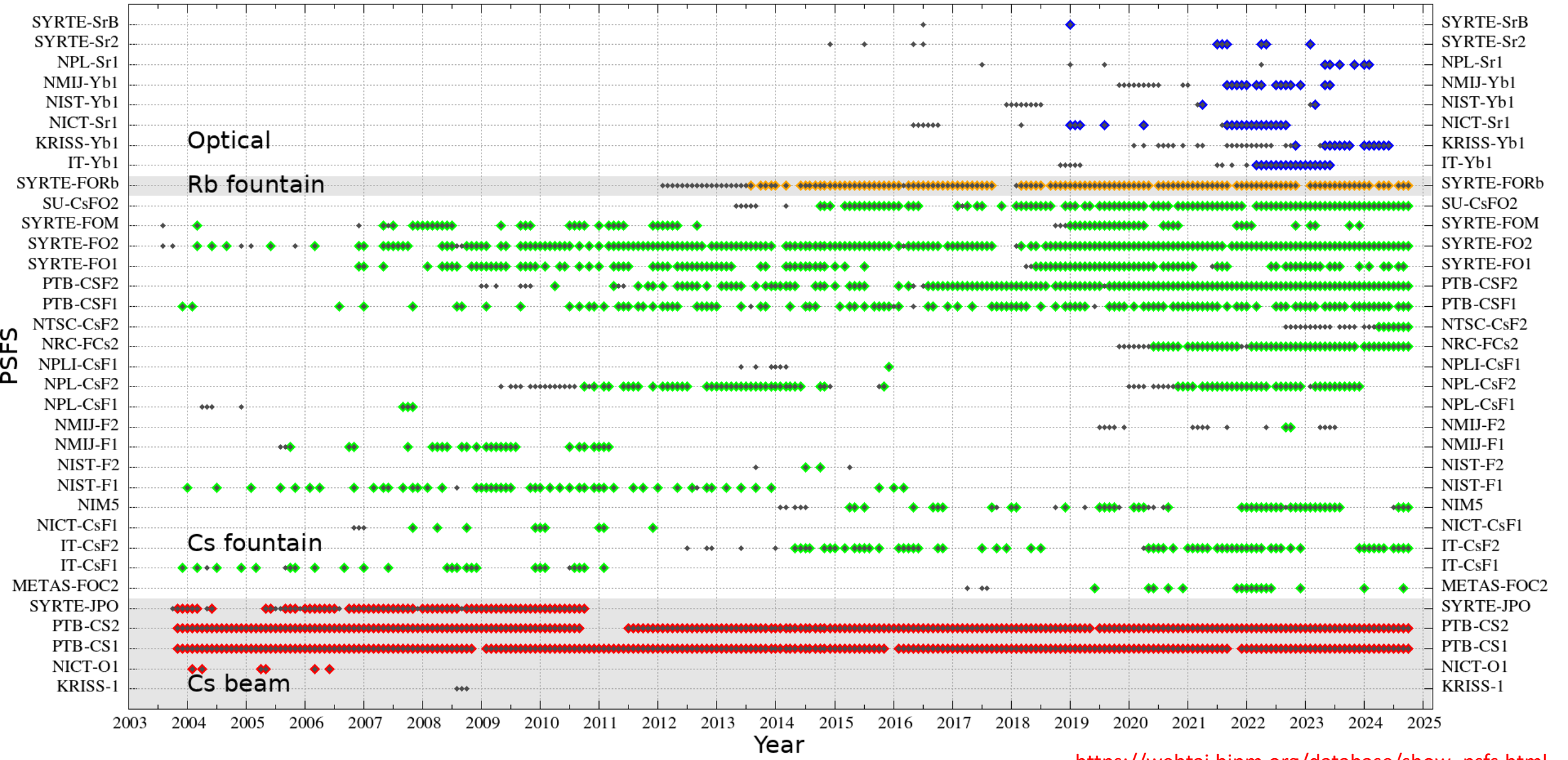


→ Will be updated for CCTF Nov. 2024

Contribution from Primary and Secondary Frequency Standards to TAI



https://webtai.bipm.org/database/show_psfs.html

Options for the redefinition

Option 1: Fix the frequency of a **single (optical) atomic transition** $\nu_{\mathrm{Xv}} = N$ Hz

Example: $\nu_{^{87}\mathrm{Sr}}$ = 429 228 004 229 873.0 Hz or $\nu_{^{171}\mathrm{Yb}}$ = 518 295 836 590 863.5 Hz or other species/transition

Option 2: Fix an artificial frequency from the weighted geometric mean of frequencies for an **ensemble of transitions**

$$\prod_i \nu_i^{w_i} = N \text{ Hz} \quad (\text{with} \sum_i w_i = 1)$$

Example: $(\nu_{^{87}\mathrm{Sr}})^{0.25}(\nu_{^{171}\mathrm{Yb}})^{0.25}(\nu_{^{171}\mathrm{Yb}^+(\mathrm{E3})})^{0.2}(\nu_{^{27}\mathrm{Al}^+})^{0.3} = 650\ 464\ 137\ 090\ 812.53$ Hz

Two studied sub-options :

2.1 The species / transitions and their weights are fixed at the time of redefinition

2.2 The species / transitions and/or their weights can be updated after the redefinition (following predefined rules) to take into account future progress (→ "dynamic" definition)

~~Option 3: Choose another **fundamental constant**, playing the same role of c, h, e, k in the current definition of SI units~~

Example: $m_e = 9.1093837015 \times 10^{-31}$ kg.

Not realistic on short term because to date, fundamental constants are known with a too large uncertainty

Options for the redefinition

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→ Ongoing analysis of Pros and Cons of Options 1 and 2

Species and transitions achievements wrt criteria targets on OFS

Draft version
August 2024

Species ordered by ascending transition frequencies	Number of systems / institutes developing OFS	I.1 - OFS accuracy budgets		I.2 - Validation of accuracy budgets		I.3 - Continuity with the current definition		I.4 – Calibration of TAI
		Lowest u_B /1E-18	Number of groups with uncertainty ≲ 2E-18 (+ number with larger uncertainty but ≲ 1E-17)	Same clock comparisons to ≲ 5E-18	Frequency ratio measurements to ≲ 5E-18	Measurements vs Cs to <5E-16	SRS recommended uncertainty (CIPM 2021)	Number of calibrations of the TAI scale interval
^{40}Ca+ 411 THz	3 systems / 1 institute	3	1 (+1)	(1 comp. ≲ 7.5E-18)	0 meas. ≲ 5E-18 (1 meas. ≲ 2. 10-16)	1 meas. to 3.2E-16, 2 meas. close to 5E-16	1.8E-15	
^{87}Sr 429 THz	18 systems / 12 institutes	0.81	1 (+5)	2 comp. ≲ 5E-18 (discrepancies)	2 meas. ≲ 8E-18 (+4 meas.<1E-16)	8 meas. vs Cs to <5E-16	1.9E-16	31 by 3 institutes (no calibration that meets the requirement ≤ 2E-16)
^{88}Sr 429 THz	2 institutes	20	0 (+0)		0 meas. ≲ 5E-18 (2 meas. ≲ 3E-17)		2.0E-16	
^{88}Sr^{+} 445 THz	7 systems / 5 institutes	10	0 (+2)		0 meas. ≲ 5E-18 (1 meas. ≲ 2. 10-17)	1 meas. vs Cs to <5E-16 1 meas. close to 5E-16	1.3E-15	
^{171}Yb 518 THz	8 systems / 7 institutes	1.4	1 (+2)	1 comp. ≲ 10-18	2 meas. ≲ 6.8E-18 +1 meas. to 8.8E-17	3 meas. vs Cs to <5E-16	1.9E-16	45 by 4 institutes (no calibration that meets the requirement ≤ 2E-16)
^{171}Yb^{+}(E3) 642 THz	3 institutes	2.7	1 (+0)	1 comp. ≲ 5. 10-18	0 meas. ≲ 5E-18 (3 meas. ≲ 3.4E-17)	3 meas. vs Cs to <5E-16	1.9E-16	
^{171}Yb+(E2) 688 THz	3 systems / 2 institutes	33	0 (+0)		0 meas. ≲ 5E-18 (1 meas. ≲ 3.4E-17)	2 meas. vs Cs close to 5E-16	2.0E-16	
^{199}Hg+ 1065 THz	0	19	0 (+0)		0 meas. ≲ 5E-18 (1 meas. ≲ 5.2E-17)	1 meas. vs Cs at 6.5E-16	2.2E-16	
^{27}Al^{+} 1121 THz	4 institutes	0.94	2 (+1)		0 meas. ≲ 5E-18 (2 meas. ≲ 2E-17)	1 meas. vs Cs to <5E-16	1.9E-16	
^{199}Hg 1129 THz	1 institute	72	0 (+0)		0 meas. ≲ 5E-18 (3 meas. ≲ 1E-16)	1 meas. vs Cs to <5E-16	2.4E-16	

Species and transitions achievements wrt criteria targets on OFS

Draft version August 2024

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^{199}Hg 1129 THz	1 institute	72	0 (+0)		0 meas. ≲ 5E-18 (3 meas. ≲ 1E-16)	1 meas. vs Cs to <5E-16	2.4E-16	

Towards a redefinition of the second

CGPM 2022

Resolution 5 : ”bring proposals to the 28th meeting of the CGPM (2026) for the **choice of the preferred species, or ensemble of species** for a new definition of the second, and for the **further steps** that must be taken for a **new definition to be adopted at the 29th meeting of the CGPM (2030)**”

Possible steps (details to be confirmed at CCTF 2025)

CGPM 2026

Short list of possibilities for a new definition of the second **+ roadmap to converge** to a preferred possibility in 2027-2028

Detailed and realistic action plan to fulfil criteria + NMI commitment on the required actions (more OFS with accuracy in the 10^{-18} range, more comparison campaigns with fibre links or transportable clocks, more OFS contributing regularly to TAI calibration)

CCTF 2027-2028

Final choice of the species or ensemble of species

Assurance that mandatory criteria will be fulfilled before 2030

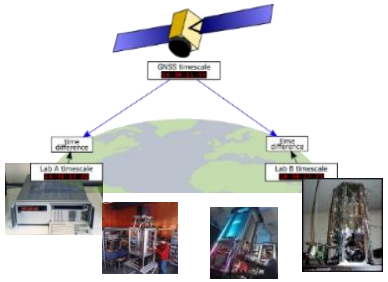
CGPM 2030

Redefinition of the second: Mandatory criteria fulfiled + Validation of the chosen option/species/transition(s)

Continuous UTC

23:59:59
23:59:60
00:00:00

Construction of the Coordinated Universal Time UTC



National time laboratories realize real-time approximations **UTC(k)**

~ 450 atomic clocks
in ~ 85 laboratories
+
~ 15 primary frequency standards
in ~ 13 laboratories

TAI

International Atomic Time

Measurement of Earth's rotation UT1 (by IERS - International Earth Rotation and Reference Systems Service)

leap seconds

UTC

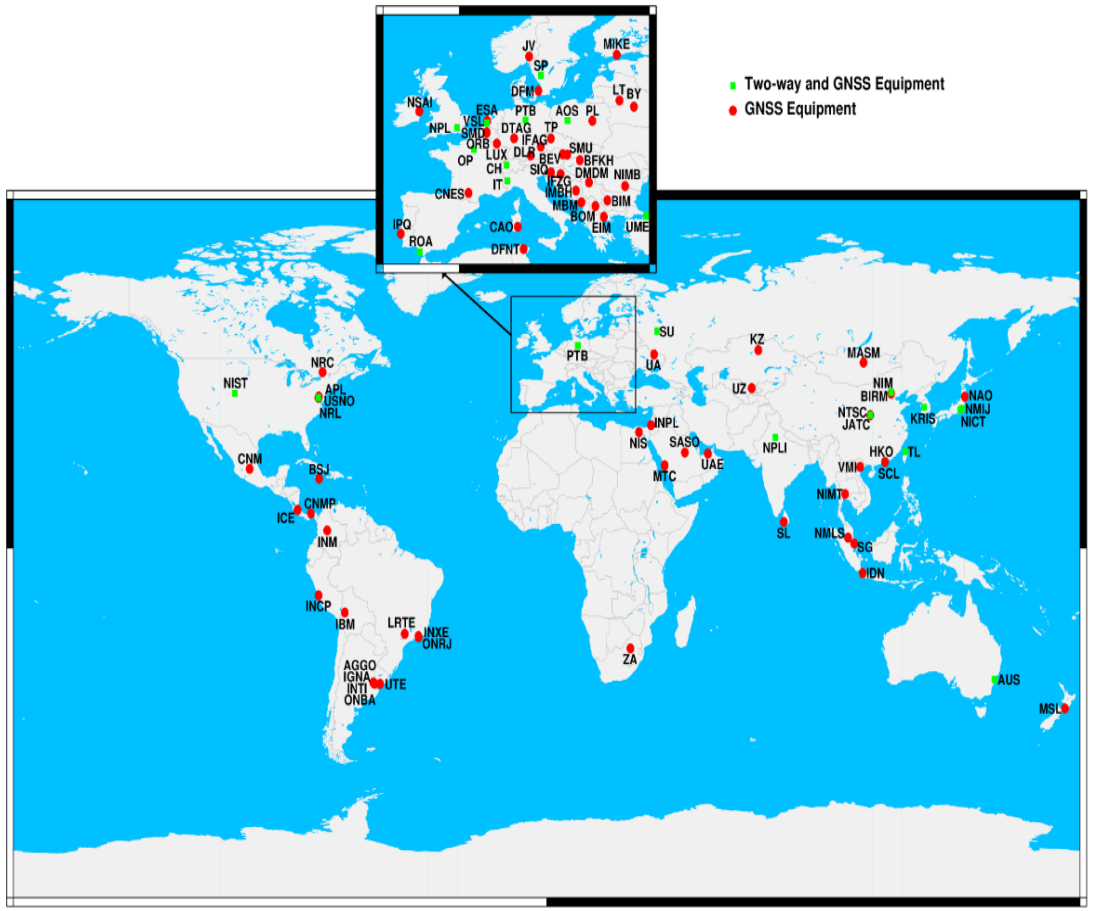
Coordinated Universal Time

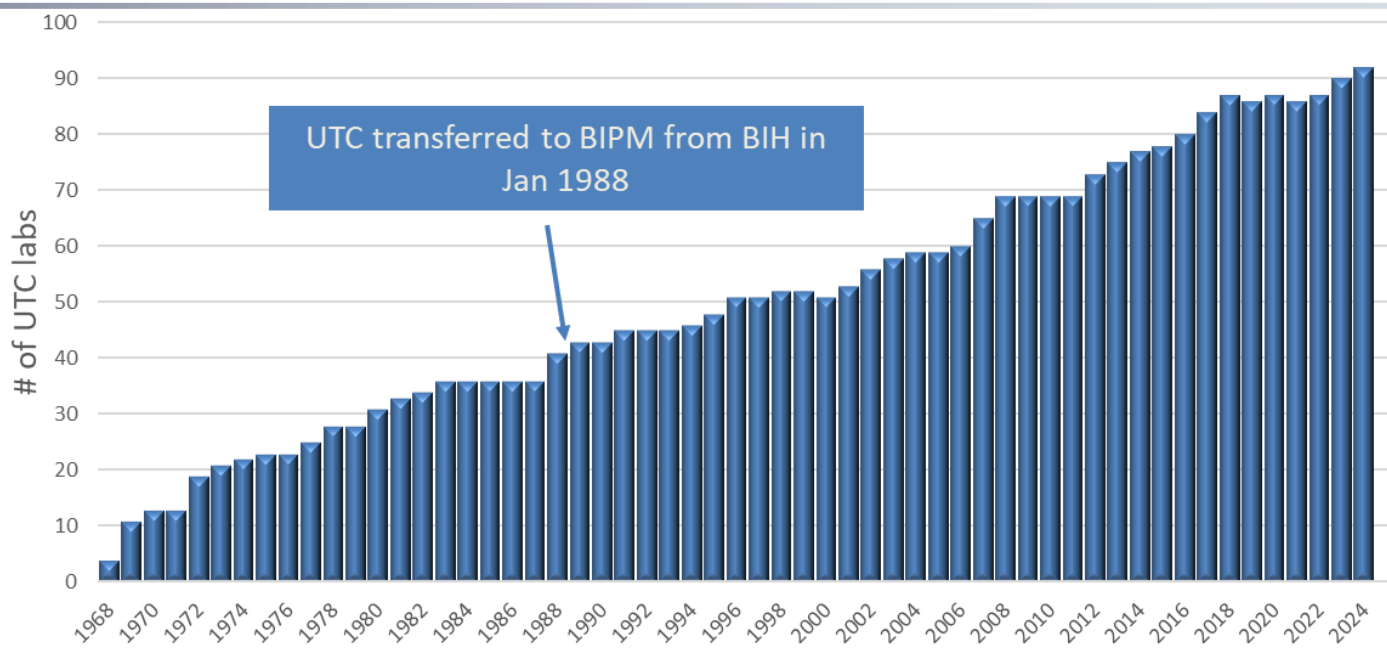
|UT1 – UTC| < 1 s

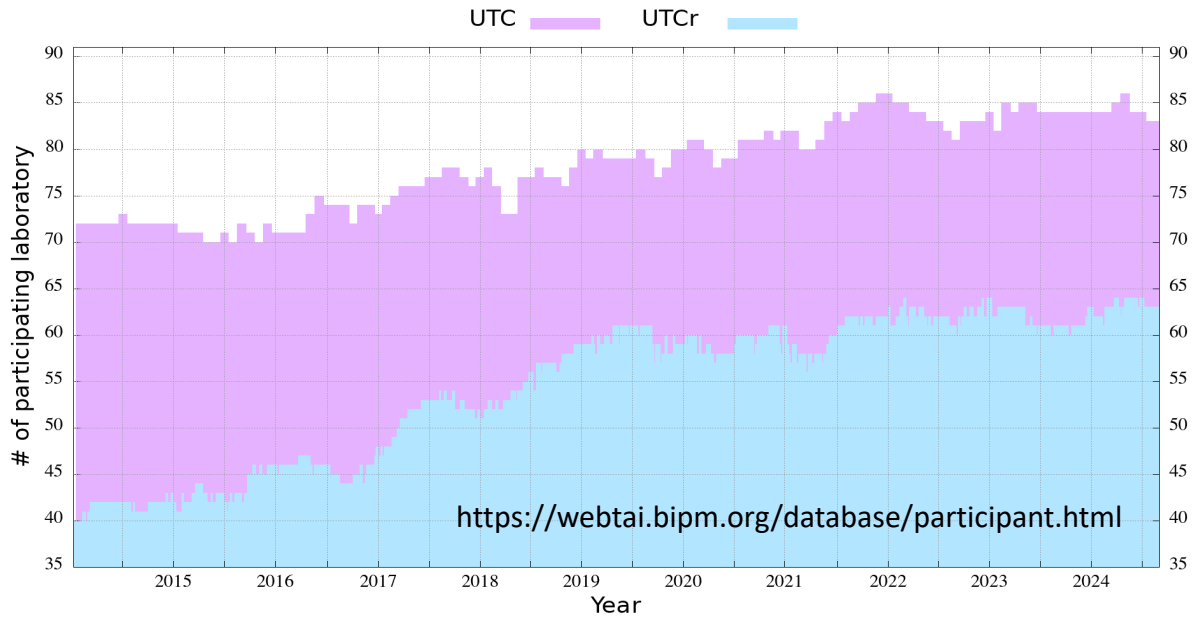
The offset [***UTC*** - ***UTC(k)***] is published in **BIPM *Circular T***

UTC definitive results each month
UTC Rapid solution each week
UTC(k) are national realizations in real time

Worldwide contributions to UTC (≈ 85 labs each month)



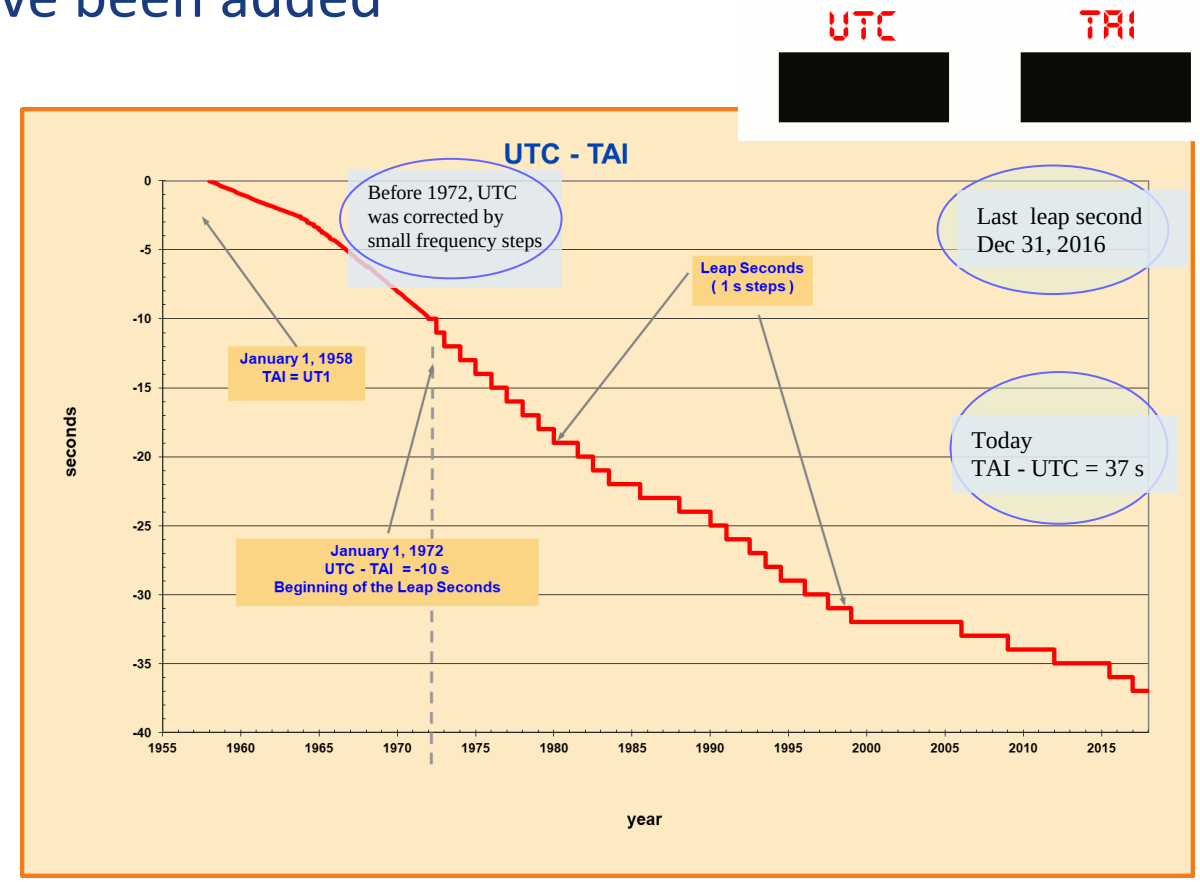




Current situation with leap seconds

Leap seconds to keep UTC in agreement with the rotational angle of the Earth UT1 (within 1 s)
Today TAI-UTC = 37 s (last leap second on Dec. 31, 2016)
Till now, only positive leap seconds have been added

23:59:59
23:59:60
00:00:00



But all systems underpinning critical infrastructures need a continuous time scale!

The process to insert the leap second and the code to transmit DUT1= UT1-UTC are described in Rec ITU-R TF 460-6

The digital networks cannot cope with unpredictable leap seconds

WIRED

The Inside Story of the Extra Second That Crashed the W

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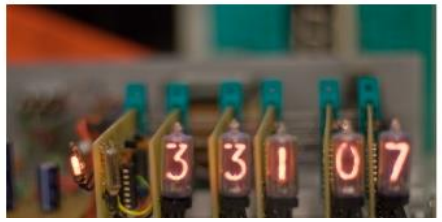
ROBERT MCMILLAN AND CADE METZ BUSINESS 07.02.12 07:54 PM

The Inside Story of the Extra Second That Crashed the Web



自由時報

Liberty Times Net

https://3c.ltn.com.tw/news/18985/2

61 seconds in a minute? Understand the computer and the stock market enemy "leap second"

2015/07/01 06:27

Text/Reporter Liu Jiqing

Leap second hits Qantas air bookings, while Reddit and Mozilla stutter

The addition of an extra second between Saturday and Sunday to account for the slowing rotation of the Earth affected flight check-ins in Australia, and hit popular websites including Yelp and Foursquare

More than 400 Qantas flights were delayed when the 'leap second' confused web servers on Sunday. Photograph: Mark Baker/AP

The Telegraph

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Leap Second confuses Twitter and Android

Users reported problems with Android and Twitter as the leap second was added to atomic time

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'Leap second' snafu affects Oracle clusterware

By Chris Kanaracus

U.S. Correspondent, IDG News Service | JANUARY 06, 2009 12:00 AM PT

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Time Waits for No One: 'leap Seconds' May Be Cut | Security Implications of the Humble Computer Clock | The Big Promise of Big Data | Hadoop Enhance

NEWS

Leap Second Bedevils Web Systems Over Weekend

Reddit, LinkedIn and other sites were knocked offline by an extra second added to the official time

By Joab Jackson

U.S. Correspondent, IDG News Service | JULY 02, 2012 08:00 AM PT

Time travels on the network

Computer operating systems are not easily able to handle a minute with 61 seconds

Important steps forward towards a continuous UTC

CGPM
General Conference on Weights and Measures
27th meeting - 15-18 November 2022

- **CGPM 2022 Resolution 4 - On the use and future development of UTC**

  decides that the **maximum value for the difference (UT1-UTC) will be increased in, or before, 2035,**

  requests that the CIPM consult with the ITU, and other organizations that may be impacted by this decision in order to

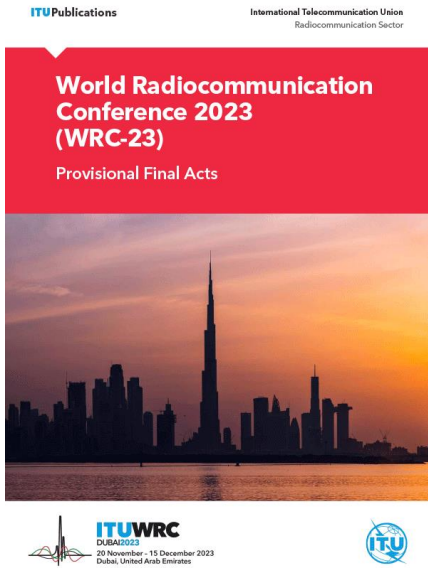
  - **propose a new maximum value for the difference (UT1-UTC) that will ensure the continuity of UTC for at least a century,**
  - prepare a **plan to implement by, or before, 2035 the proposed new maximum** value for the difference (UT1-UTC),

  ……

  encourages the BIPM to work with relevant organizations to identify the need for updates in the different services that disseminate the value of the difference (UT1-UTC) and to ensure the correct understanding and use of the new maximum value.

- **Approval of this change by ITU in Nov. 2023, with an implementation in 2035**

Thanks to all the NMIs that have worked with their national ITU delegation



To be proposed for approval at the CGPM 2026

- **Extended tolerance for UTC – UT1: 3 options**
  - **1 minute** (or a few minutes) *- in 100 years?*
  - **1 hour** (connected to daylight saving time) *- in 3000-5000 years?*
  - **no limit** fixed yet (next generations will decide when to align UTC to UT1)

➡ Please bring the voice of the users in your countries to take the most useful decision on the new tolerance UT1-UTC

- **Date of implementation of the new limit (in or before 2035)**:
  - ITU and some countries recommend 2035 to have time to update technological systems but other countries and user communities are urging the change
  - An important risk of a negative leap second could definitely push towards a quicker change

↳ Need to estimate the probability for a negative leap second over the next decade:
- CCTF TG + Discussions with IERS
- Different predictions from experts
- Workshop planned in Spring 2025

Risk for a negative leap second during the next decade?

March 27 on Nature: UTC as now defined will require a negative discontinuity by 2029 (could have been in 2026)
https://www.nature.com/articles/d41586-024-00850-x

Article

A global timekeeping problem postponed by global warming

https://doi.org/10.1038/s41586-024-07170-0
Received: 4 August 2023
Accepted: 6 February 2024
Check for updates

Duncan Carr Agnew[1]

The historical association of time with the rotation of Earth has meant that Coordinated Universal Time (UTC) closely follows this rotation[1]. Because the rotation rate is not constant, UTC contains discontinuities (leap seconds), which complicates its use in computer networks[2]. Since 1972, all UTC discontinuities have required that a leap second be added[3]. Here we show that increased melting of ice in Greenland and Antarctica, measured by satellite gravity[4,5], has decreased the angular velocity of Earth more rapidly than before. Removing this effect from the observed angular velocity shows that since 1972, the angular velocity of the liquid core of Earth has been decreasing at a constant rate that has steadily increased the angular velocity of the rest of the Earth. Extrapolating the trends for the core and other relevant phenomena to predict future Earth orientation shows that UTC as now defined will require a negative discontinuity by 2029. This will pose an unprecedented problem for computer network timing and may require changes in UTC to be made earlier than is planned. If polar ice melting had not recently accelerated, this problem would occur 3 years earlier: global warming is already affecting global timekeeping.

We MAY HAVE OR WE MAY NOT HAVE a negative leap

Why the timekeeping and GNSS communities should start preparing.

DEMETRIOS MATSAKIS, MASTERCLOCK

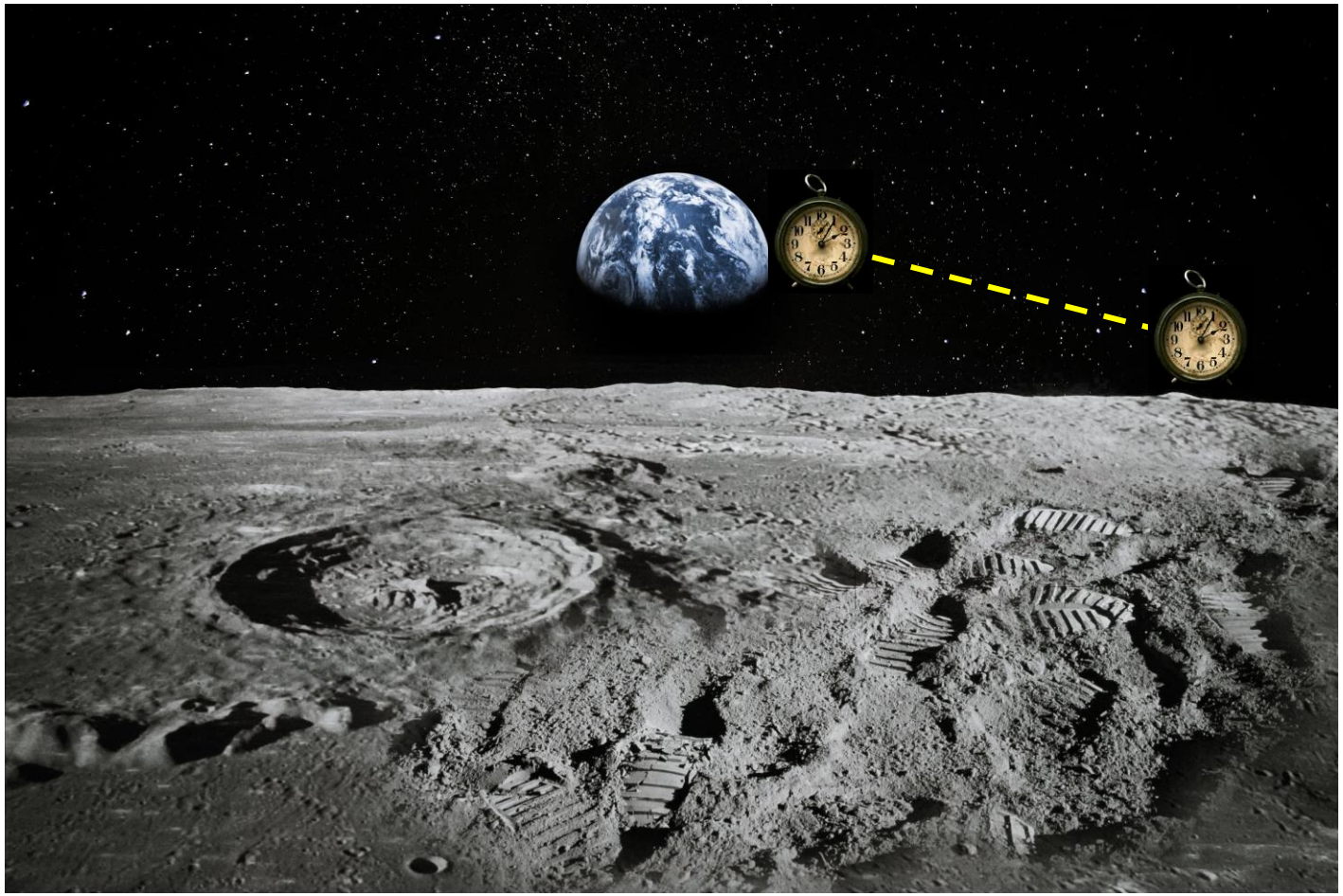
DENNIS MCCARTHY, U.S. NAVAL OBSERVATORY, CONTRACTOR

https://insidegnss.com/will-we-have-a-negative-leap-second/

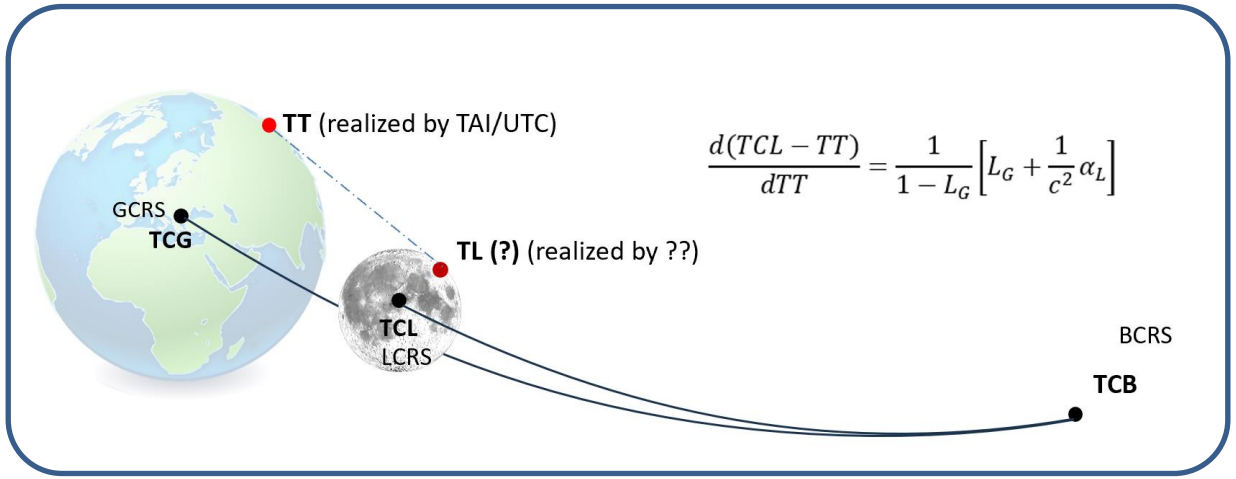
No reliable prediction is possible in the long term, let's observe the Earth rotation and let's the future generations decide

L. Zotov, C. Bizouard, C.K. Shum, C. Zhang, N. Sidorenkov, V. Yushkin, "Analysis of Earth's polar motion and length of day trends in comparison with estimates using second degree stokes coefficients from satellite gravimetry", *Advances in Space Research* **69**, 308–318 (2022). https://doi.org/10.1016/j.asr.2021.09.010

Lunar reference time

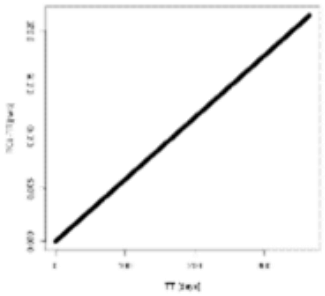


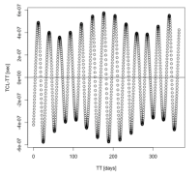
Need for a common Lunar reference time for numerous upcoming/recent projects for Moon exploration…



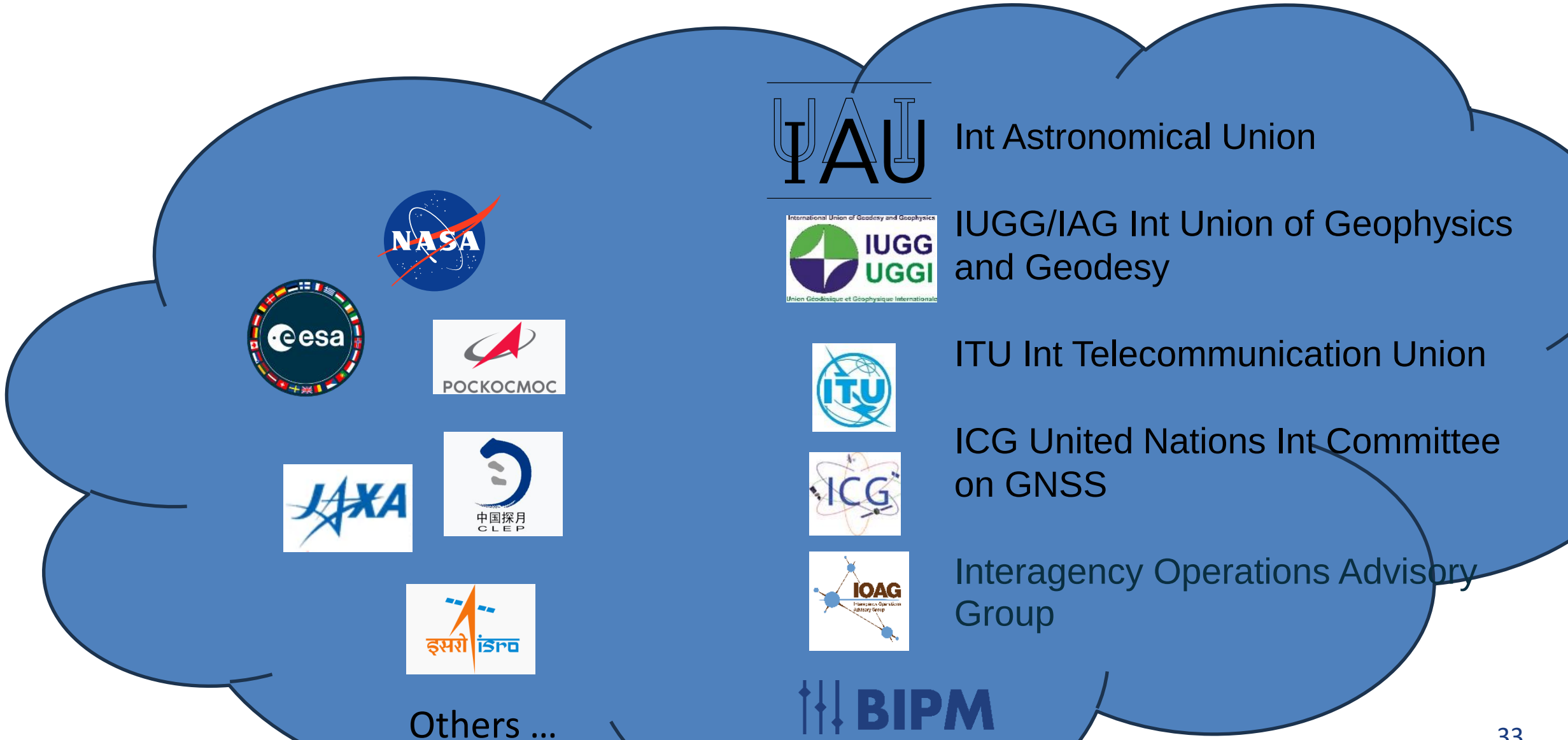
→ **Time difference between a clock on the selenoid and a clock on the geoid:**

Time drift (56 µs/day) + **Periodic terms (amplitude about 0.6 µs)**





Moon (and Mars?) decisions involve multiple actors



Several activities going on in International Organizations

- **IAU International Astronomical Union**
  - Commission A3 Standards prepared two Resolutions adopted by the IAU General Assembly in Aug 2024.
  - WG "Time Metrology Standards« chaired by F. Meynadier and G. Petit (BIPM), and subgroup on lunar timescale
  - IAU Symposium: “Advancing Reference Systems, Ephemerides, and Standards: from the Earth and the Moon to solar system bodies” August 2025
- **IAG International Association of Geodesy**
  - WG1.1.3: Lunar Reference Frames is working on a Lunar Reference frame as ITRF and look for support on lunar timing
- **ITU International Telecommunication Union - Radiocommunication**
  - WP7A and 7B « Time and frequency services" and "Science" are discussing the frequency bands to be used on the Moon
- **ICG International Committee on GNSS and IOAG Interagency Operations Advisory Group**
  - ICG Working Group-L on Lunar PNT
  - Workshop on Moon PNT in Feb 2025 in Wien
- **CCTF - BIPM**
  - Task group gathering National Metrology Institutes from countries / continents involved in Moon missions
  - Organization of a workshop with IOs and space organizations
- **Others?**

Recent steps forward

IAU General Assembly 2024 resolutions

- **Resolution II**: Defines a standard Lunar Celestial Reference System and associated coordinate time (*Built on previous 1991 and 2000 IAU resolutions concerning all bodies of the Solar System)*
- **Resolution III**: Encourages the establishment of a lunar reference time scale by international agreement

Considers *that Coordinated Universal Time (UTC), as established by the Bureau International des Poids et Mesures (BIPM) based on international collaboration and coordination, has been a successful worldwide reference time scale for operational systems in the near-Earth environment,*

Recommends *the relationships between the possible versions of a lunar reference time scale and other time scales, in particular a lunar coordinate time and UTC, are pursued in collaborative agreement among the relevant international organizations.*

Work plan of ICG Working Group-L on Lunar PNT (Oct. 2024)

The Working Group must coordinate, as needed, with other ICG Working Groups and with external international organizations, such as the Bureau International des Poids et Mesures (BIPM), …

→ The BIPM has already been explicitly called twice in official recommendations of other organizations

Towards a resolution at the CGPM 2026?

Work together with concerned International Organization for common agreement:

Decision on reference time scales impacts several fields of applications and activities in the realm of different international organizations

It is important to define common and agreed reference standards ensuring interoperability and comparability of measurements

Clear and traceable connection to UTC of any time scale on the Moon:

The theoretical behavior of a Lunar time scale versus TT/UTC should be known (in the frame of General Relativity)

When feasible, the difference between the realizations of the time scales should be measured with a clear process for uncertainty evaluation

CCTF

Thank you for your attention

Bureau International des Poids et Mesures