CCTF

24th Meeting of the Directors of NMIs and Member State Representatives
October 16-17, 2025

Report from the CCTF
Proposals for resolutions at the CGPM

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

Bureau International des Poids et Mesures

Content

- **Introduction – CCTF Strategy**
- **Redefinition of the second**
- **Continuous UTC**
- **Lunar reference time**

CCTF – Consultative Committee for Time and Frequency

CCTF created by the CIPM in 1997, succeeding the Consultative Committee for the Definition of the Second (CCDS) that was set up in 1956.

- **25 institutes as Members *(+1 in 2025)***
- **3 institutes as Official Observers *(+2 in 2025)***
- **+ institutes as Invited Observers**
- **5 Liaisons (IAU, IGS, ITU-R, IUGG, URSI)**
- **+ guests + CCTF WG chairs + BIPM staff**

(~ 95 participants)

One meeting online / year since 2020

<u>24th Meeting of the CCTF:</u>

- Session 1: 14,15,21,22 November, 2024 (online)

- Session 2: 18-19 September 2025 (60 participants in-person + 35 online)

CCTF Strategy and Activities

Updated CCTF Strategy 2025-2035 covering:

- **Matters in Time and Frequency (TF) metrology:**
  - **Definition and *mise en pratique* of the SI second**
  - **Atomic frequency standards**
  - **TF transfer techniques**
  - **Establishment and diffusion of international atomic time scales**
  - **Metrological traceability**

- **Cross-cutting topics**
  - **Redefinition of the second**
  - **Continuous UTC**
  - **Lunar Reference time**
  - **Traceability to UTC from GNSS measurements**
  - **Sharing resources to improve (inter)national timekeeping**
  - **Digitalization**
  - **Quantum Technologies**

→ CGPM 2026 resolutions

CCTF

Strategy 2025-2035
Consultative Committee for Time and Frequency (CCTF)

Table of Content

CCTF organization

CCTF-WGSP (Extended to TG/SG co-chairs)
CCTF WORKING GROUP ON STRATEGIC PLANNING

Nominal WGs

- CCL-CCTF-WGFS – CCL-CCTF WORKING GROUP ON FREQUENCY STANDARDS
- CCTF-WGATFT – CCTF WORKING GROUP ON COORDINATION OF THE DEVELOPMENT OF ADVANCED TIME AND FREQUENCY TRANSFER TECHNIQUES
- CCTF-WGMRA – CCTF WORKING GROUP ON THE CIPM MRA
- CCTF-WG-ALGO – CCTF WORKING GROUP ON TIME SCALE ALGORITHMS
- CCTF-WGGNSS – CCTF WORKING GROUP ON GNSS TIME TRANSFER
- CCTF-WGPSFS – CCTF WORKING GROUP ON PRIMARY AND SECONDARY FREQUENCY STANDARDS
- CCTF-WGTAI – CCTF WORKING GROUP ON TAI
- CCTF-WGTWSTFT – CCTF WORKING GROUP ON TWO-WAY SATELLITE TIME AND FREQUENCY TRANSFER

Transverse TF, TGs

- TF Redefinition of the second / 3 SGs: Options, Criteria, Education and communication
- TG Continuous UTC
- TG Promoting the mutual benefit of UTC and GNSS
- TG Lunar reference time
- TG Digitalization
- TG Quantum Technologies
- Coordination on Capacity building - Sharing resources

Thanks to the actors and contributors

Great thanks to:

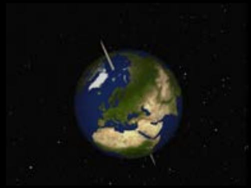
- (co)Chairs and members of the CCTF working groups / task groups for their strong involvement that maintains the momentum and ensures rapid progress in all CCTF topics

- 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

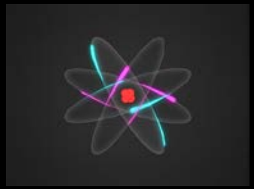
- BIPM Director and Time Department for their outstanding support to CCTF activities

Redefinition of the SI second

Before 1967
Duration of the
solar day / tropical year




Since 1967
Resonance frequency of
Cs atom



In 2030?

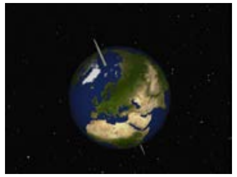
?

Definitions of the SI unit of time

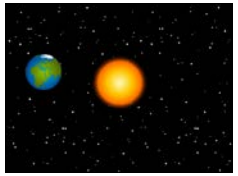
The SI unit of time – the second – is defined as:

Astronomy

→ **until 1956**: *the fraction 1/86 400 of the mean solar day*

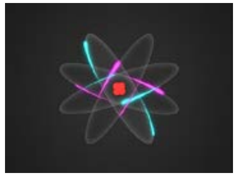


→ **1956 to 1967**: *the fraction 1/31,556,925.9747 of the tropical year 1900*
(1 tropical year = 365,2422 solar days = 366,2422 sideral days)



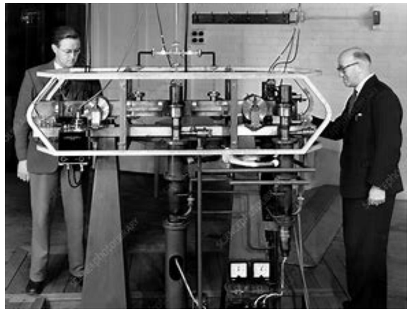
Quantum physics

→ **1967**: *the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom*
Added in 1999: This definition refers to a cesium atom at rest at a temperature of 0 K



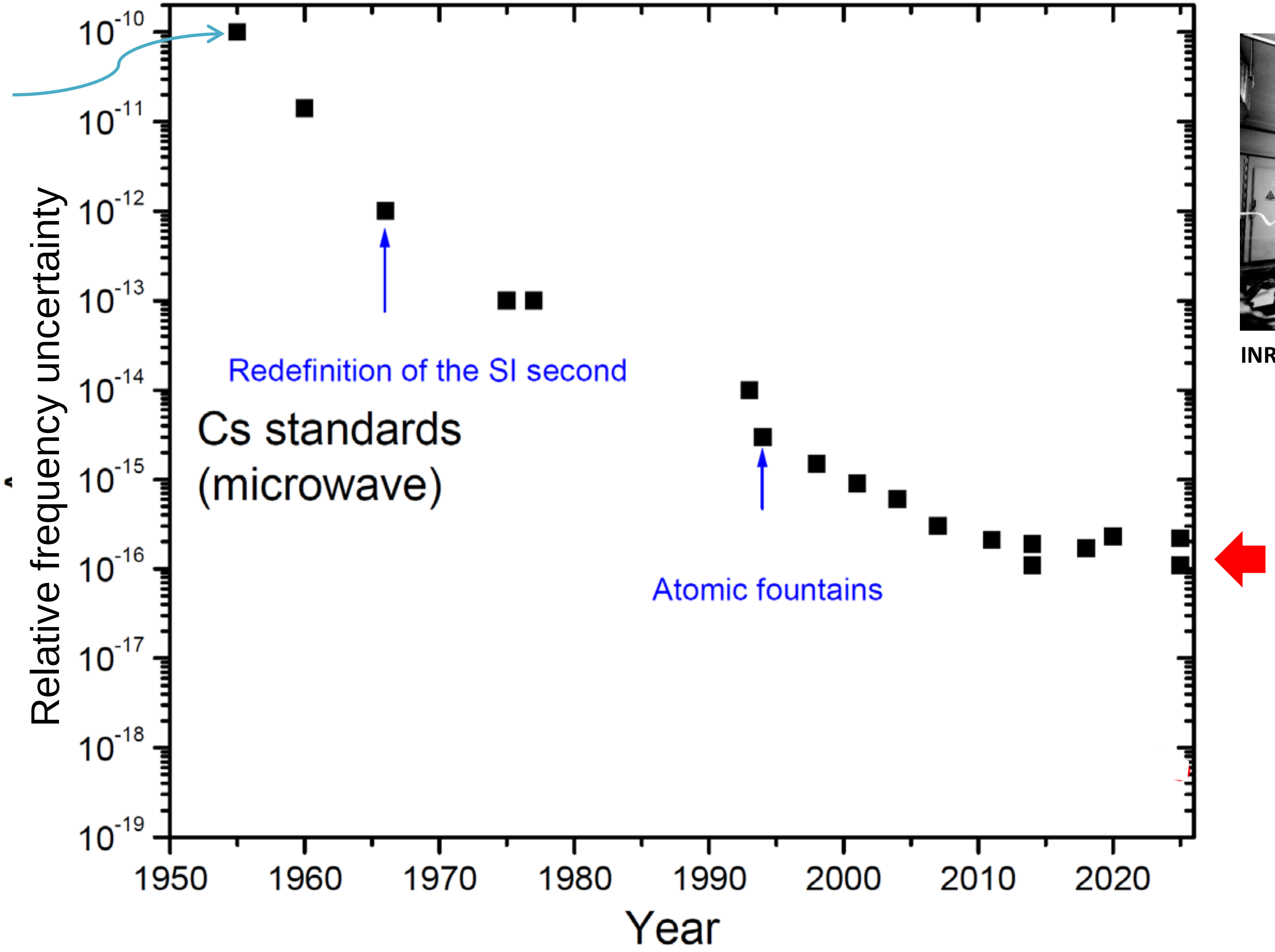
New formulation in 2018:
The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.

Realization of the SI second with primary Cs frequency standards

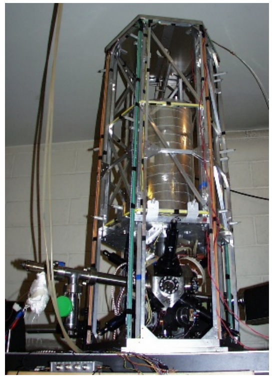


First Cs frequency standard (NPL)

Cs atomic beam frequency standard (PTB)



INRIM



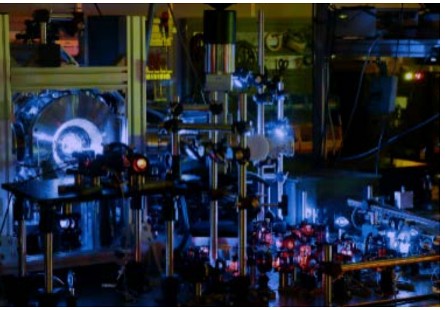
LNE-OP

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

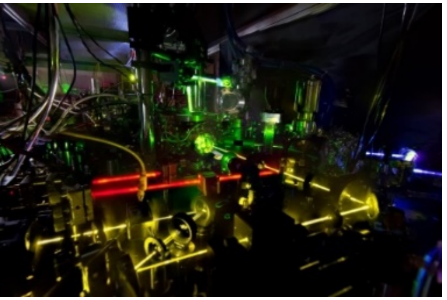
NIM

Bureau International des Poids et Mesures

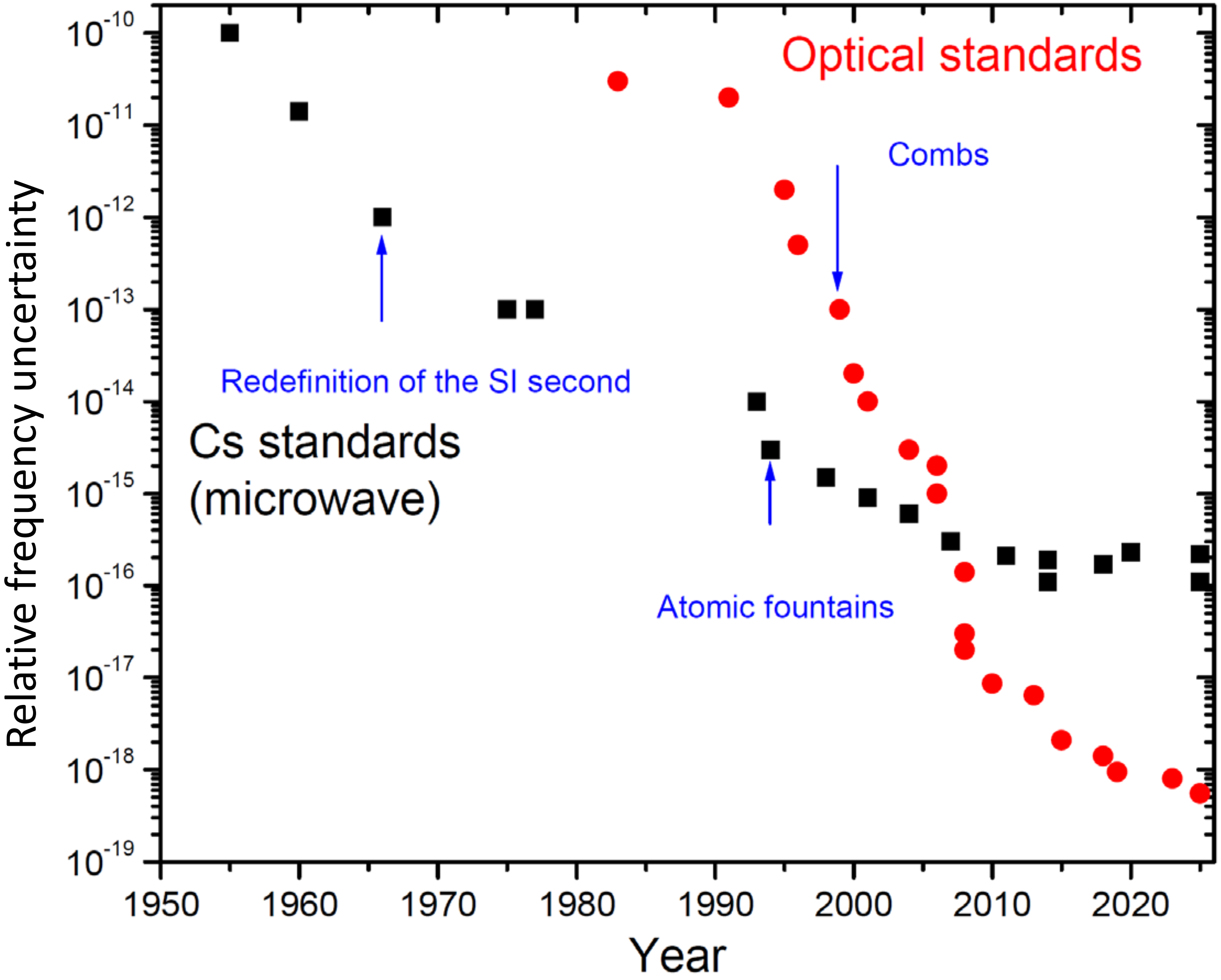
Optical Frequency Standards are surpassing Cs clocks



Sr lattice Clock (NICT)



Yb Lattice Clock (NIST)



> 50 Optical Frequency Standards in operation or under development in > 20 institutes, with > 12 different species / transitions: Sr, Yb, Hg, Yb+, Al+, Ca+, In+, Sr+, …
with best **uncertainty < 10^{-18} level**
(0.1 ps / day
3 ns / 100 years)

27th 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

2025 updated version of the roadmap towards the redefinition of the second:

- Towards the choice of the new definition
- Towards the fulfilment of mandatory criteria to ensure readiness of OFS and T/F transfer techniques at the time of the definition
- Towards the understanding, the acceptability and the broad utilization of the new definition

CCTF

Roadmap towards the redefinition of the SI second

September 2025 update

Content

Options for the redefinition

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

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

Option 2: Define a fictive frequency from the weighted geometric mean of frequencies for an **ensemble of transitions**

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

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

Two studied sub-options :

2.a The species and their weights are fixed at the time of redefinition

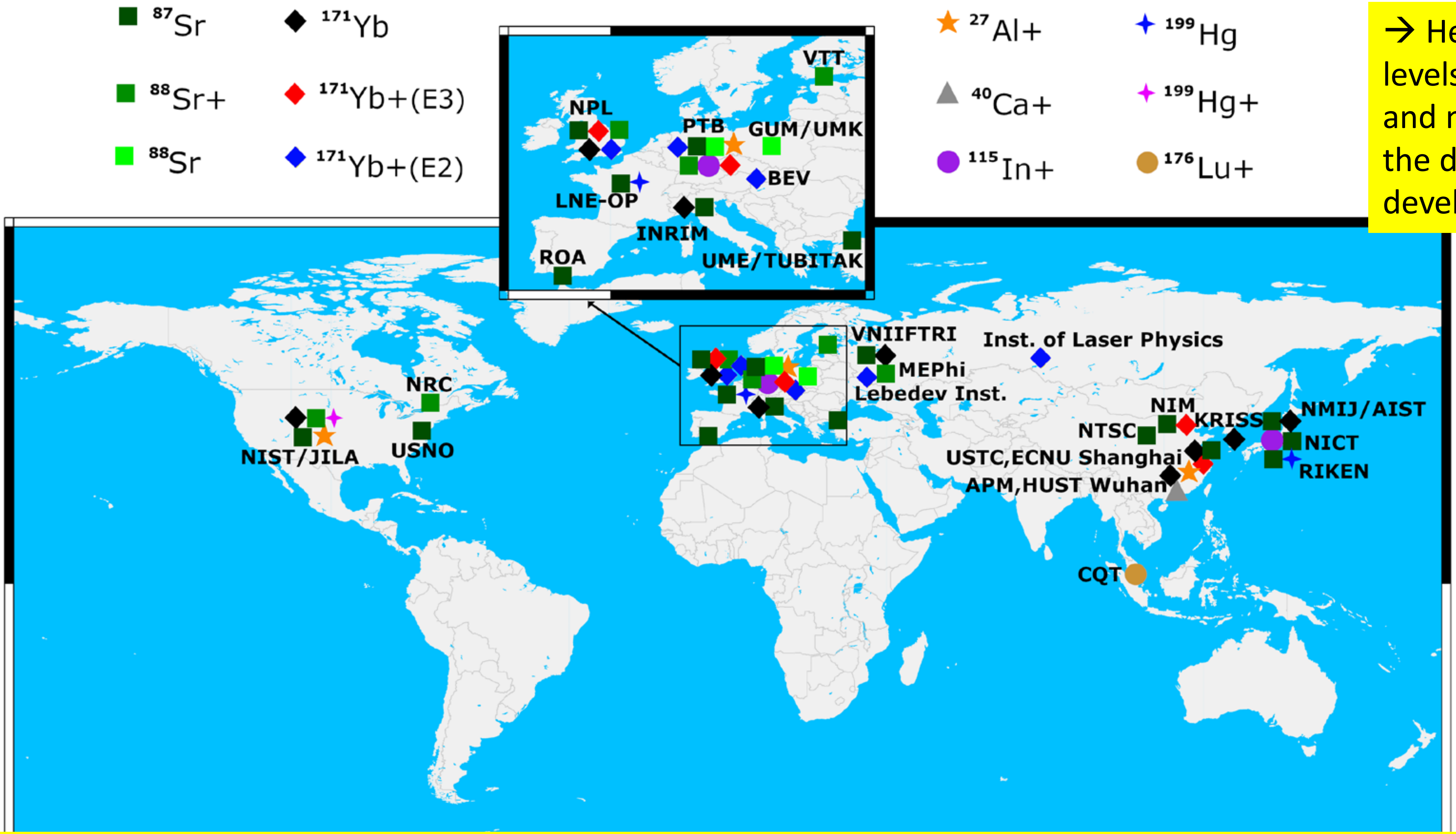
2.b The species and/or their weights can be updated (but following predefined rules) to take into account future progress (→ "dynamic" definition)

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

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

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

Optical Frequency Standards developments (2025)



→ Heterogeneous levels of progress and maturity for the different developments

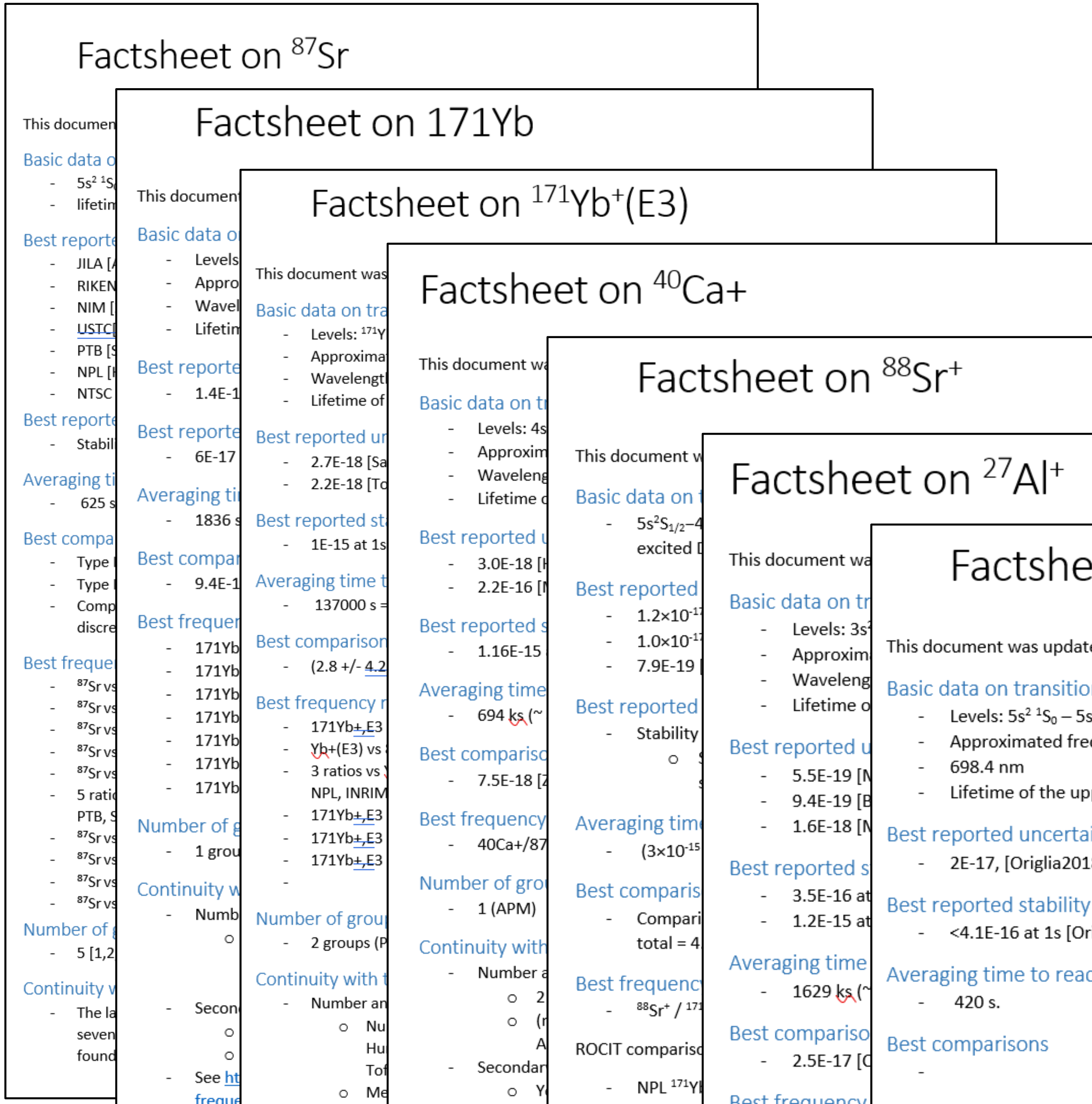
+ Other on-going, planned or envisaged developments: CENAM (Sr), INPL/ Ben Gurion (Yb), METAS, ORB, PTB (Thorium), …

Thanks to L. Tisserand (BIPM Time depart.) for the maps

Updated roadmap: towards the choice of the new definition

Choice of the possibility

Species factsheets



Updated roadmap: towards the choice of the new definition

Choice of the possibility

Species factsheets

Table 1 – Status of OFS
Factual analysis of species / radiations

		I.1 - OFS accuracy budgets		I.2 - Validation of accuracy budgets		I.3 - Continuity with the current definition		I.4 – Calibration of TAI
Species ordered by ascending transition frequencies	Number of systems / institutes developing OFS	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	Direct measurements vs Cs to <5E-16	SRS recommended uncertainty (CIPM 2021 & → 2025)	Number of calibrations of the TAI scale interval delivered on time the next month
^{40}Ca+ 411 THz	4 systems / 1 institute	3	1 (+1)	(1 comp. ≲ 7.5E-18)	0 meas. ≲ 5E-18 (1 meas. ≲ 2.4E-16)	2 meas. to <4.1E-16, 2 meas. close to 5E-16	1.8E-15 →5.5E-16	
^{87}Sr 429 THz	23 systems / 15 institutes	0.81	2(+5)	2 comp. ≲ 5E-18 (inconsistencies)	2 meas. ≲ 5.4E-18 + 2 meas. ≲ 8E-18 (+7 meas.<5E-17)	8 meas. vs Cs to <5E-16	1.9E-16 →1.7E-16	33 by 3 institutes (most calibrations do not meet the requirement ≤ 2E-16)
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^{115}In+ 1267 THz	2 systems / 2 institute	2.5	1 (+0)		1 meas. ≲ 5E-18 (1 meas. ≲ 2.9E-17)	1 meas. vs Cs to <5E-16	→1.8E-16	

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Updated roadmap: towards the choice of the new definition

Choice of the possibility

Species factsheets

↓

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↓

Table 1b – OFS achievements wrt criteria targets
Level of readiness of OFS for a redefinition in 2030

Provisional

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Updat[illegible] roadmap: towards the choice of the new definition

Provisional

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^{171}Yb+(E2) 688 THz	6 systems / 5 institutes	33	0 (+0)		0 meas. ≲ 5E-18 (2 meas. ≲ 3.4E-17)	2 meas. vs Cs close to 5E-16	2.0E-16 →1.7E-16	
^{199}Hg+ 1065 THz	1 system / 1 institute	19	0 (+0)		0 meas. ≲ 5E-18 (1 meas. ≲ 5.2E-17)	1 meas. vs Cs at 6.5E-16	2.2E-16 →2.5E-16	
^{27}Al^{+} 1121 THz	4 systems / 3 institutes	0.94	2 (+1)		0 meas. ≲ 5E-18 (2 meas. ≲ 2E-17)	1 meas. vs Cs to <5E-16	1.9E-16 →1.9E-16	
^{199}Hg 1129 THz	2 system / 2 institute	72	0 (+0)		0 meas. ≲ 5E-18 (3 meas. ≲ 1E-16)	1 meas. vs Cs to <5E-16	2.4E-16 →2.5E-16	
^{115}In+ 1267 THz	2 systems / 2 institute	2.5	1 (+0)		1 meas. ≲ 5E-18 (1 meas. ≲ 2.9E-17)	1 meas. vs Cs to <5E-16	→1.8E-16	

Updated roadmap: towards the choice of the new definition

Choice of the possibility

Provisional

Species factsheets

↓

Table 1 – Status of OFS
Factual analysis of species / radiations

↓

Table 1b – OFS achievements wrt criteria targets
Level of readiness of OFS for a redefinition in 2030

↓

Table 1c – Categorization of species

		UTC Lab	CCTF member		Mostly ready species/transitions (ordered by ascending transition frequencies)			Intermediate species/transitions (ordered by ascending transition frequencies)			Not ready species/transitions (ordered by ascending transition frequencies)				
					87Sr	171Yb	171Yb+(E3)	40Ca+	88Sr+	27Al+	88Sr	171Yb+(E2)	199Hg+	199Hg	115In+
				#institutes	15	8	4	1	6	3	2	5	1	2	2
				#systems	23	12	7	4	8	4	2	6	1	2	2
EURAMET	AT	yes		BEV								1			
EURAMET	PL	yes	yes	GUM/UMK							1				
EURAMET	IT	yes	yes	INRIM	1	2									
EURAMET	FR	yes	yes	LNE-OP	2									1	
EURAMET	UK	yes	yes	NPL	2	1	1		1			1			
EURAMET	DE	yes	yes	PTB	2		4		1	1	1	2			1
EURAMET	SP	yes	yes	ROA	1										
EURAMET	TR	yes	yes	UME/TUBITAK	1										
EURAMET	FI	yes		VTT					1						
APMP	KR	yes	yes	KRISS		1									
APMP	JP	yes	yes	NICT	1										1
APMP	JP	yes	yes	NMIJ/AIST	1	1									
APMP	JP			RIKEN	1									1	
APMP	CN	yes	yes	NIM	2		1								
APMP	CN	yes		NTSC	1										
APMP	CN			USTC, ECNU	1	1	1								
APMP	CN			APM, HUST		1		4		2					
APMP	SG			CQT											
SIM	US	yes	yes	NIST/JILA	3	3			1	1			1		
SIM	US	yes	yes	USNO	1										
SIM	CA	yes	yes	NRC					3						
COOMET	RU	yes	yes	VNIIFTRI	3	2									
COOMET	RU			Lebedev Institute								1			
COOMET	RU			ILP								1			
COOMET	RU			MEPhI					1						

Updated roadmap: towards the choice of the new definition

Provisional

		UTC Lab	CCTF member		Mostly ready species/transitions (ordered by ascending transition frequencies)			Intermediate species/transitions (ordered by ascending transition frequencies)			Not ready species/transitions (ordered by ascending transition frequencies)				
					87Sr	**171Yb**	**171Yb+(E3)**	**40Ca+**	**88Sr+**	**27Al+**	**88Sr**	**171Yb+(E2)**	**199Hg+**	**199Hg**	**115In+**
				#institutes	15	8	4	1	6	3	2	5	1	2	2
				#systems	23	12	7	4	8	4	2	6	1	2	2
EURAMET	AT	yes		BEV								1			
EURAMET	PL	yes	yes	GUM/UMK							1				
EURAMET	IT	yes	yes	INRIM	1	2									
EURAMET	FR	yes	yes	LNE-OP	2									1	
EURAMET	UK	yes	yes	NPL	2	1	1		1			1			
EURAMET	DE	yes	yes	PTB	2		4		1	1	1	2			1
EURAMET	SP	yes	yes	ROA	1										
EURAMET	TR	yes	yes	UME/TUBITAK	1										
EURAMET	FI	yes		VTT					1						
APMP	KR	yes	yes	KRISS		1									
APMP	JP	yes	yes	NICT	1										1
APMP	JP	yes	yes	NMIJ/AIST	1	1									
APMP	JP			RIKEN	1									1	
APMP	CN	yes	yes	NIM	2		1								
APMP	CN	yes		NTSC	1										
APMP	CN			USTC, ECNU	1	1	1								
APMP	CN			APM, HUST		1		4		2					
APMP	SG			CQT											
SIM	US	yes	yes	NIST/JILA	3	3			1	1			1		
SIM	US	yes	yes	USNO	1										
SIM	CA	yes	yes	NRC					3						
COOMET	RU	yes	yes	VNIIFTRI	3	2									
COOMET	RU			Lebedev Institute								1			
COOMET	RU			ILP								1			
COOMET	RU			MEPhI					1						

Precautions to be taken in the understanding and the interpretation of the ranking proposed in *Table 1.c* :

- the proposed ranking is based on the status to date (2025). Significant and fast evolutions are possible in the coming few years;
- the proposed ranking is not meant to replace formal quantitative criteria;
- in 2025, even transitions in the “Mostly ready” category are in fact quite far from meeting criteria, and it is important to note that inconsistencies have been observed in some comparisons of OFS and in the global set of frequency ratio measurements involving OFS.

Updated roadmap: towards the choice of the new definition

Choice of the possibility

Provisional

Species factsheets

↓

Table 1 – Status of OFS
Factual analysis of species / radiations

↓

Table 1b – OFS achievements wrt criteria targets
Level of readiness of OFS for a redefinition in 2030

↓

Table 1c – Categorization of species

↓

Table 2 – Draft possibilities for the redefinition

Option 1 (single species)			Option 2 (ensemble of species)
^{87}Sr	^{171}Yb	$^{171}Yb^+$(E3)	^{87}Sr, ^{171}Yb, $^{171}Yb^+$ (E3), $^{40}Ca^+$, $^{88}Sr^+$, $^{27}Al^+$, (Cs?)
~23 systems in ~15 institutes EURAMET: 9 systems in 6 institutes APMP: 7 systems in 6 institutes SIM: 4 systems in 2 institutes COOMET: 3 systems in 1 institute	**~12 systems in ~8 institutes** EURAMET: 3 systems in 2 institutes APMP: 4 systems in 4 institutes SIM: 3 systems in 1 institute COOMET: 2 systems in 1 institute	**~7 systems in ~4 institutes** EURAMET: 5 systems in 2 institutes APMP: 2 systems in 2 institutes	**~58 systems in ~20 institutes** EURAMET: 21 systems in 7 institutes APMP: 19 systems in 8 institutes SIM: 12 systems in 3 institutes COOMET: 6 systems in 2 institutes

Updated roadmap: towards the choice of the new definition

Choice of the possibility

Species factsheets

Provisional

Option 1 (single species)			Option 2 (ensemble of species)
^{87}Sr	^{171}Yb	$^{171}Yb^+$(E3)	^{87}Sr, ^{171}Yb, $^{171}Yb^+$ (E3), $^{40}Ca^+$, $^{88}Sr^+$, $^{27}Al^+$, (Cs?)
~ 23 systems in ~ 15 institutes EURAMET: 9 systems in 6 institutes APMP: 7 systems in 6 institutes SIM: 4 systems in 2 institutes COOMET: 3 systems in 1 institute	**~ 12 systems in ~ 8 institutes** EURAMET: 3 systems in 2 institutes APMP: 4 systems in 4 institutes SIM: 3 systems in 1 institute COOMET: 2 systems in 1 institute	**~ 7 systems in ~ 4 institutes** EURAMET: 5 systems in 2 institutes APMP: 2 systems in 2 institutes	**~ 58 systems in ~ 20 institutes** EURAMET: 21 systems in 7 institutes APMP: 19 systems in 8 institutes SIM: 12 systems in 3 institutes COOMET: 6 systems in 2 institutes

Table 1c – Categorization of species

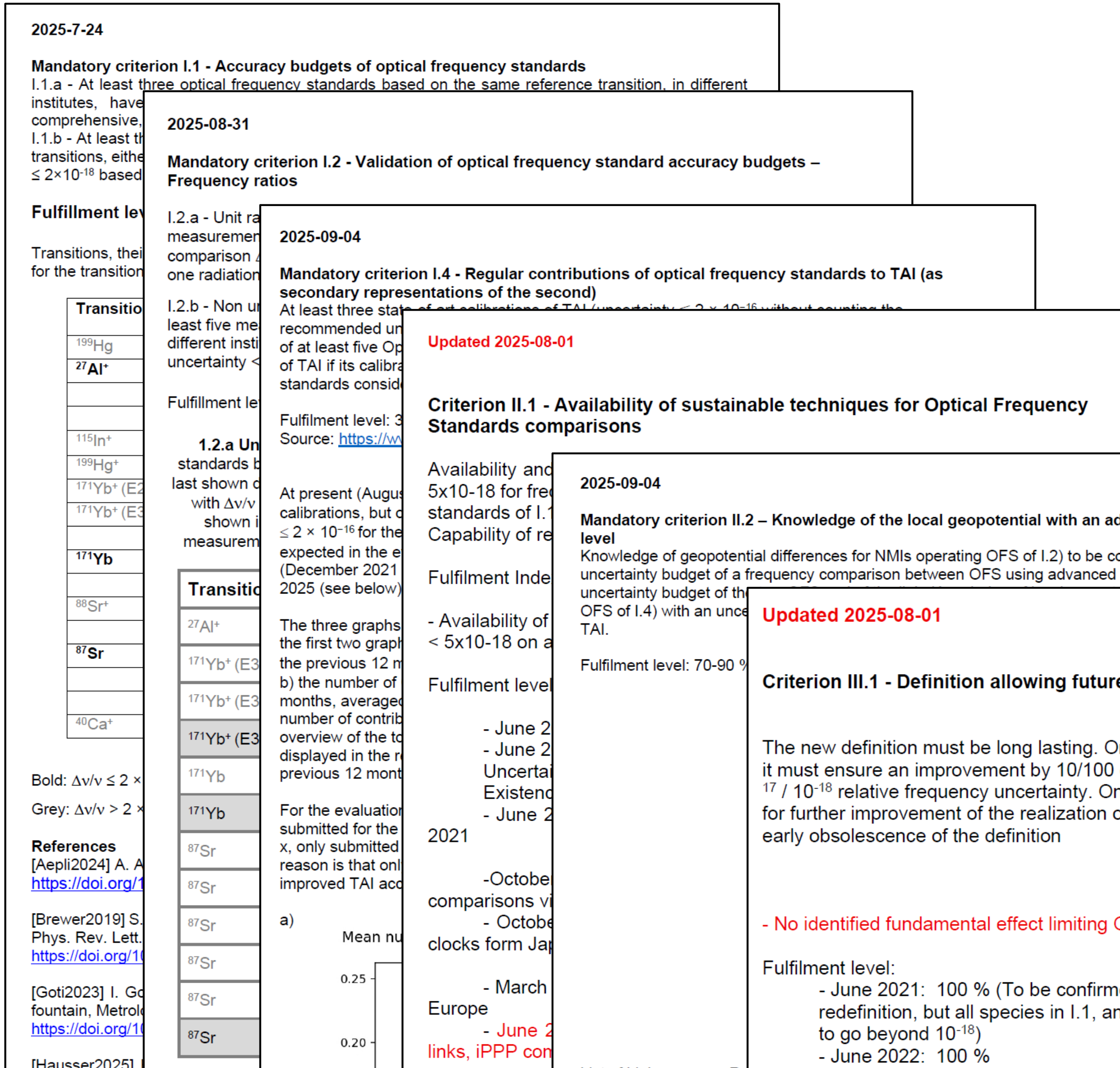
Precautions to be taken in the understanding and the interpretation of the proposed short list of possibilities for the redefinition :

- there is no ranking or preference between the 4 proposed possibilities;
- Table 2 is based on the status to date (2025) and significant and fast evolutions are possible in the coming few years, that could impact the proposed possibilities;
- in 2025, the species / transitions in Table 2 are in fact quite far from meeting criteria, and it is important to note that inconsistencies have been observed in some comparisons of OFS and in the global set of frequency ratio measurements involving OFS;
- concerning the proposed possibility based on Option 2, the interest to keep Caesium in the ensemble of species has to be confirmed. Anyway, if Caesium is not part of the ensemble of species, it will obviously be a secondary representation of the second after the redefinition.

Updated roadmap: towards the fulfilment of criteria

Fulfilment of mandatory criteria

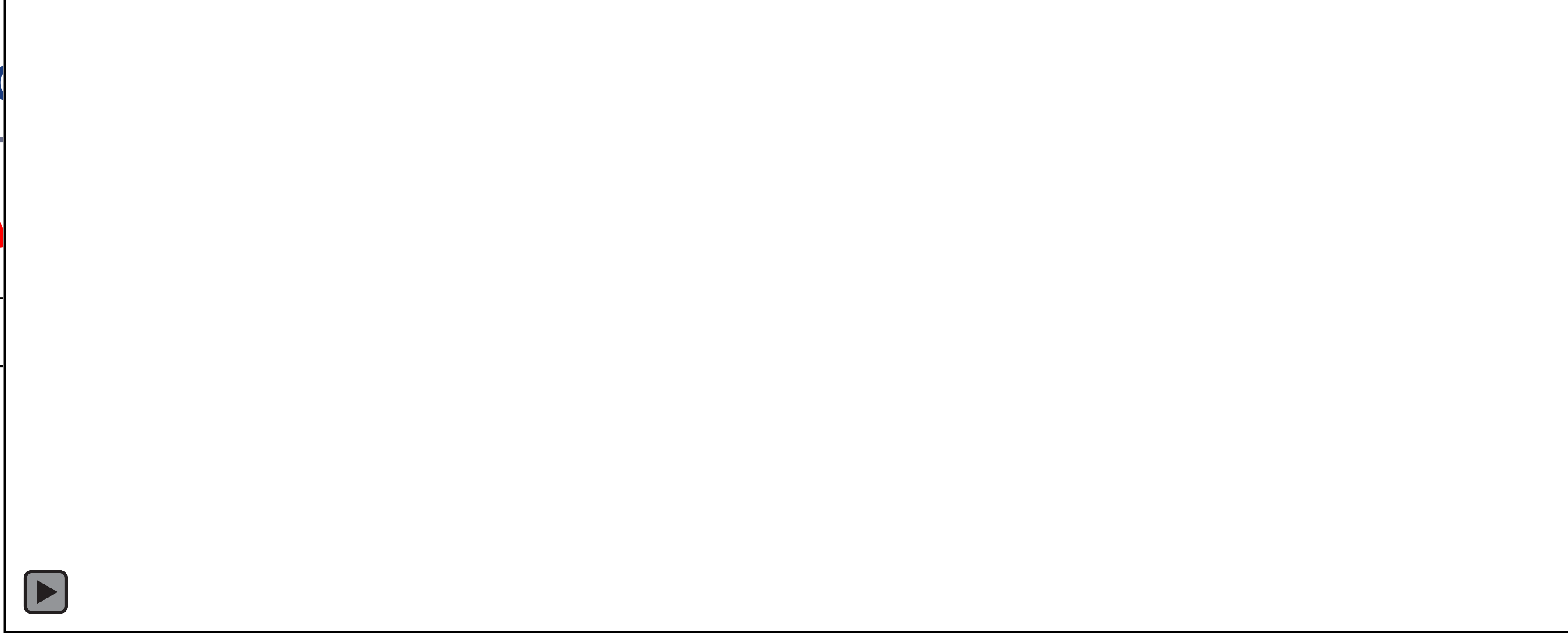
Criteria factsheets



Updated roadmap: t

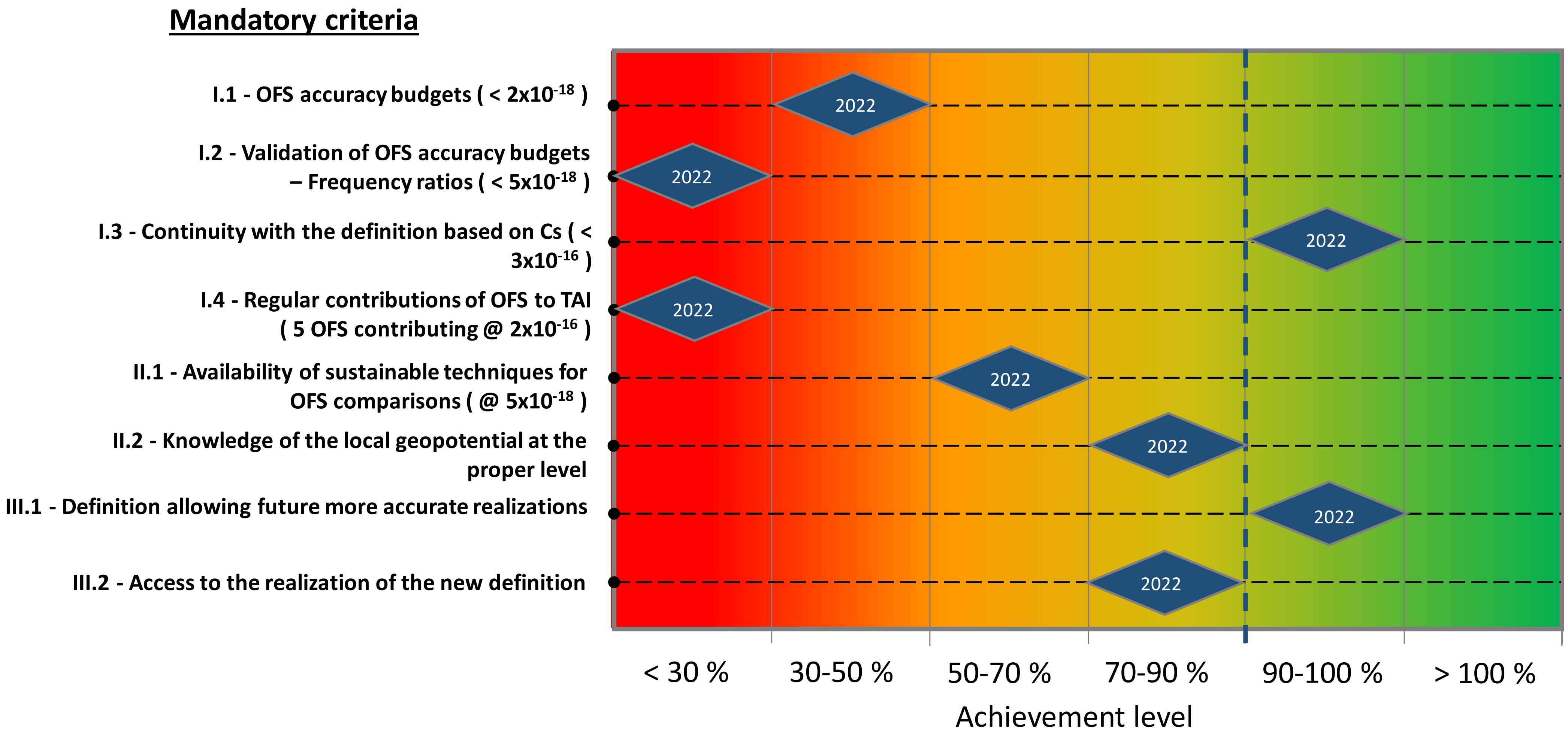
Fulfilment of mandatory

Criteria factsheets

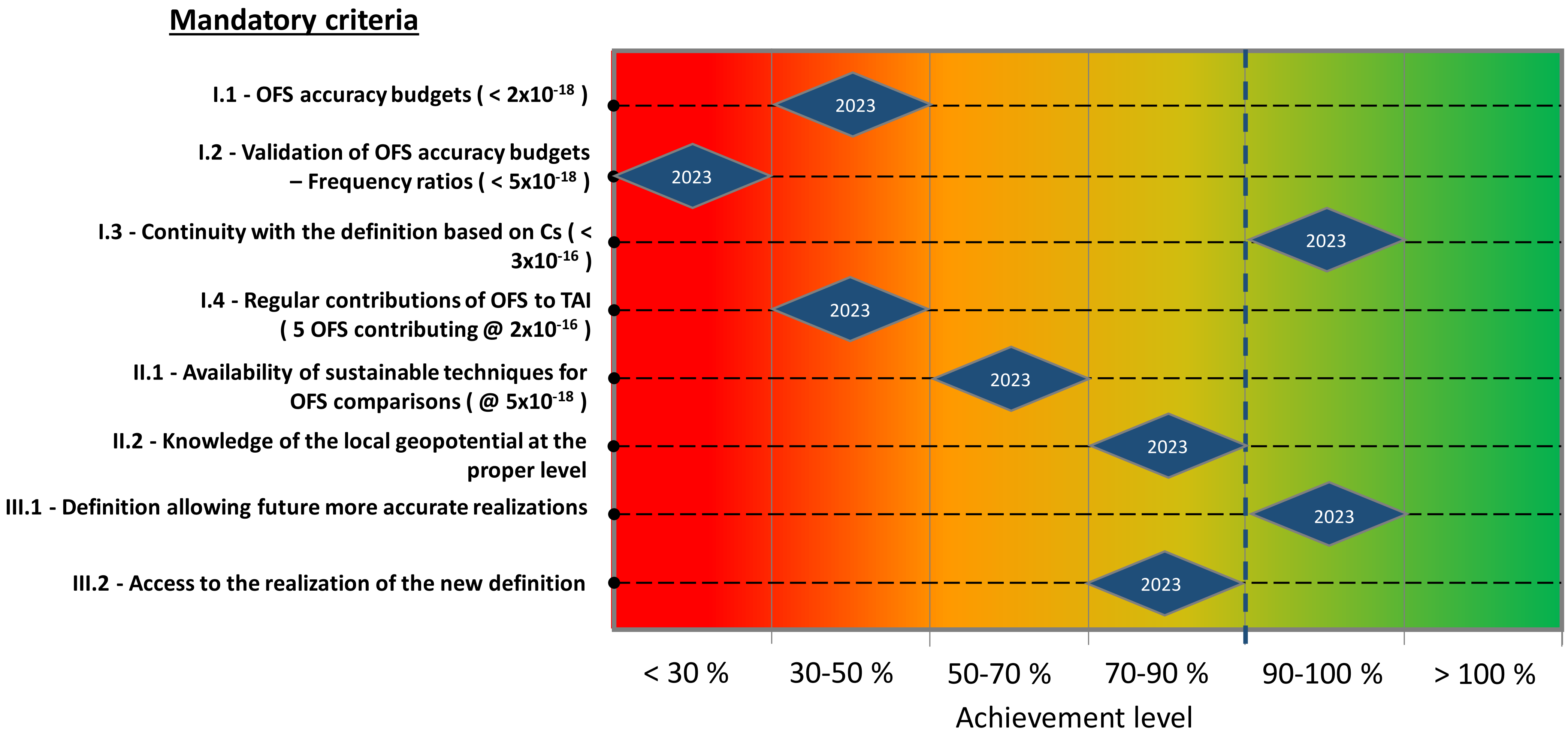


Criteria fulfilment levels diagram

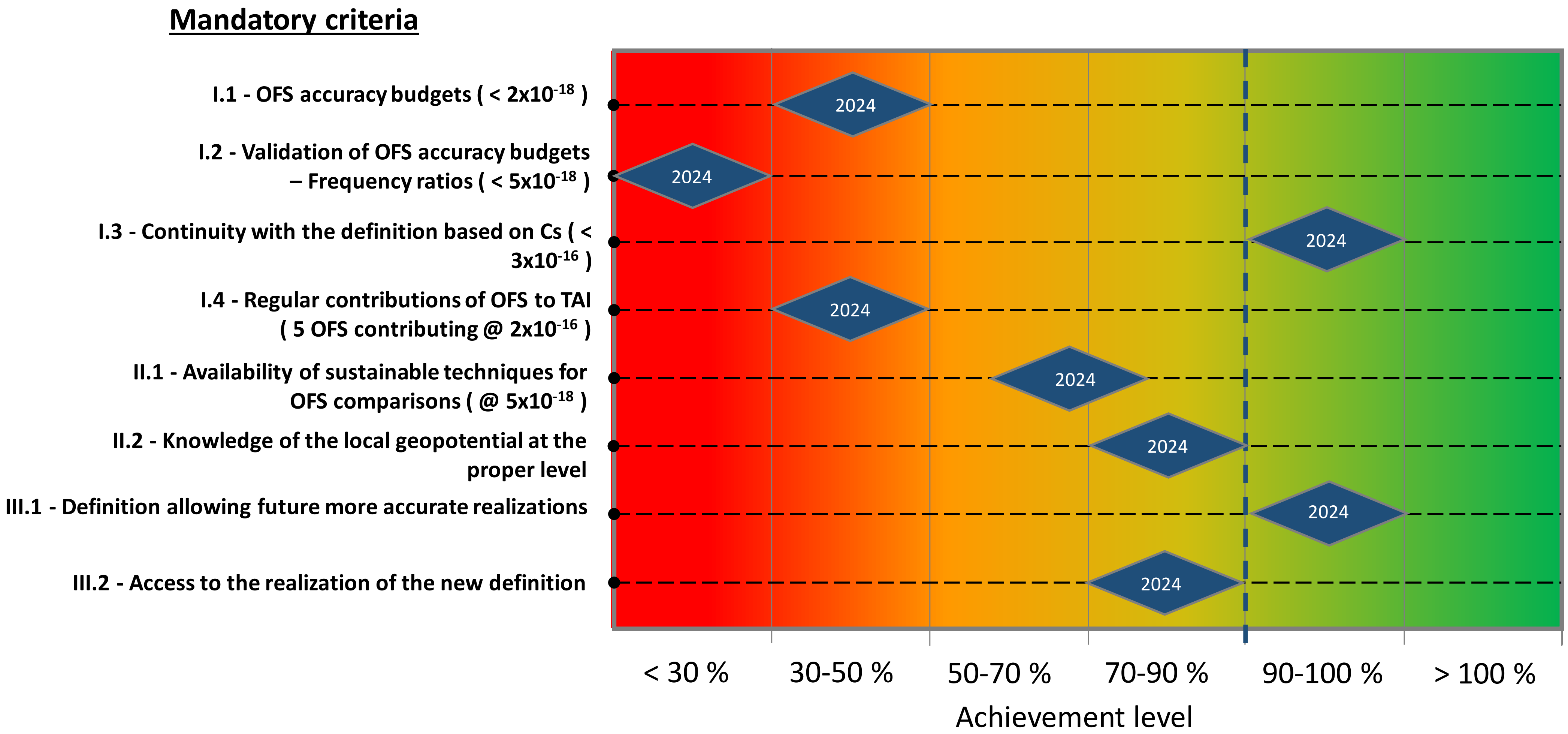
Fulfilment level of mandatory criteria (2022)



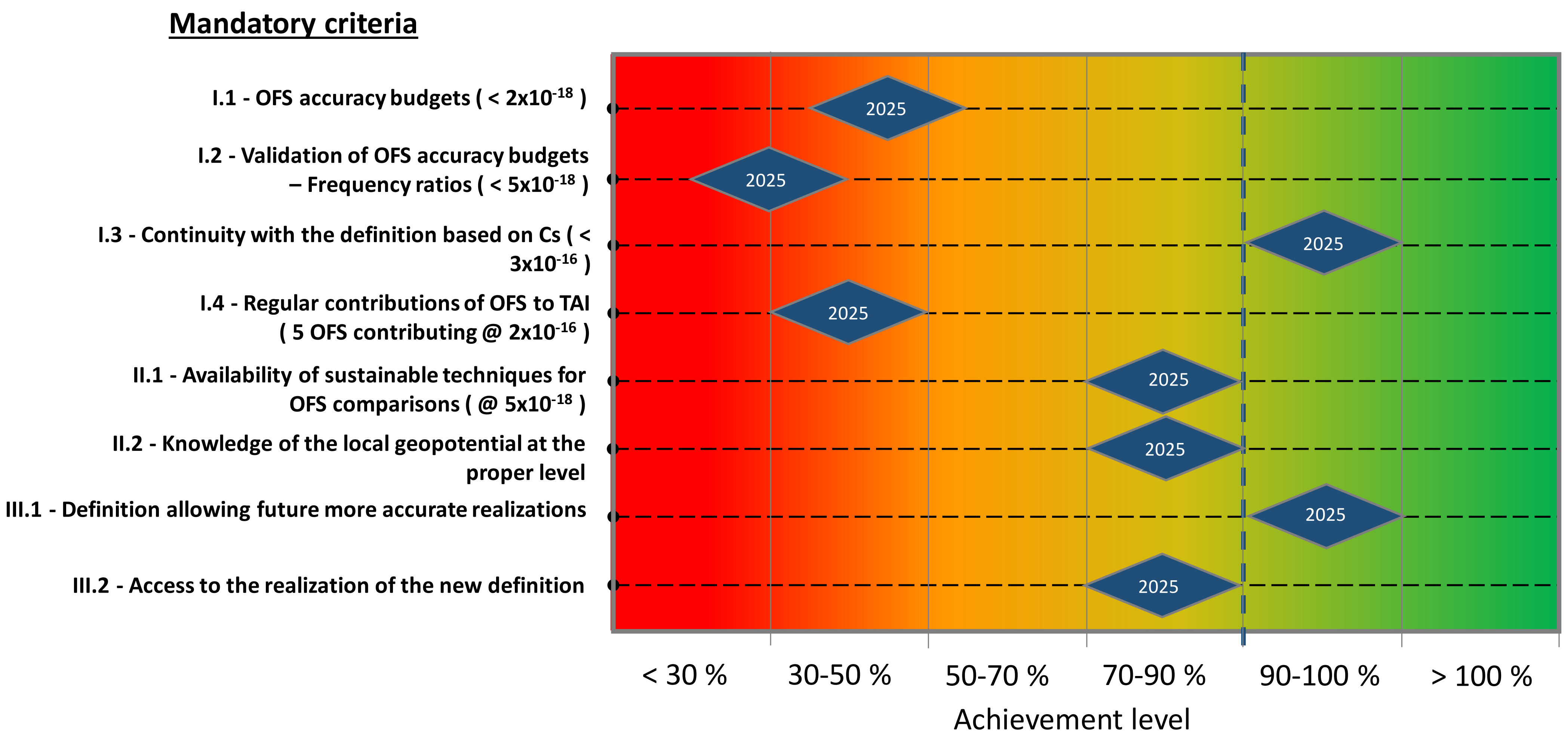
Fulfilment level of mandatory criteria (2023)



Fulfilment level of mandatory criteria (2024)



Fulfilment level of mandatory criteria (2025)



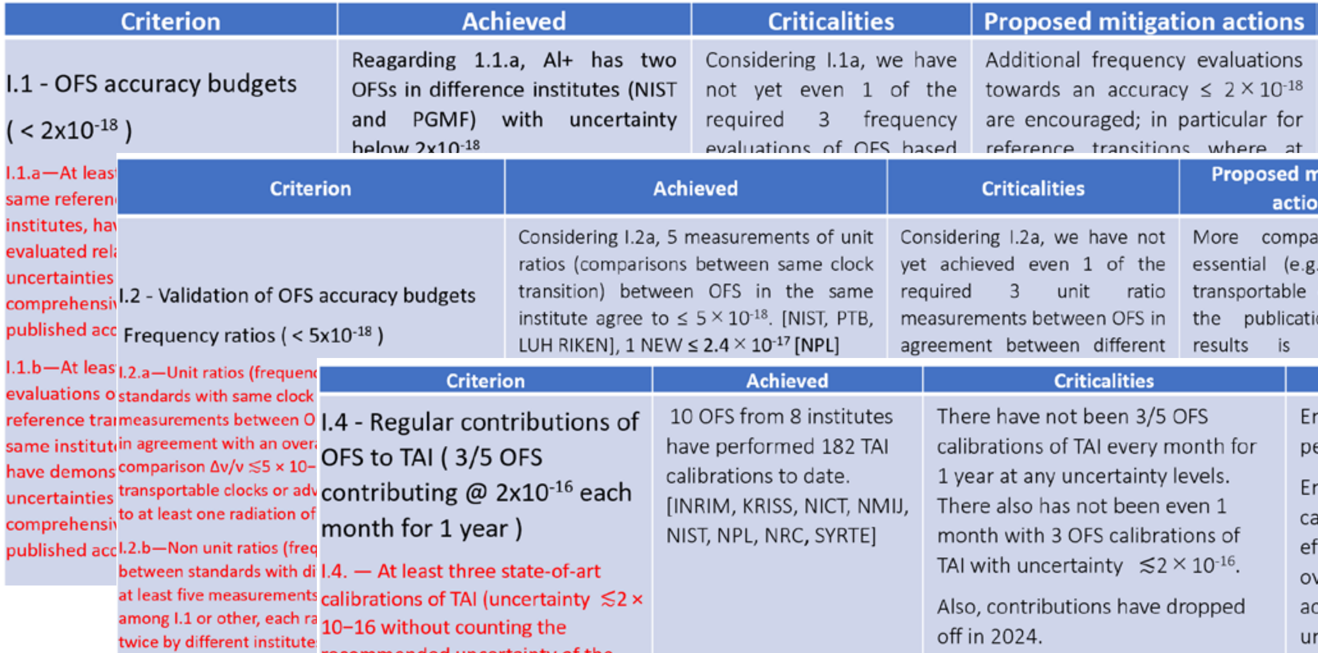
Updated roadmap: t

Fulfilment of mandatory

Criteria factsheets

Criteria fulfilment levels diagram

Table 3 – Criteria criticalities with mitigation actions



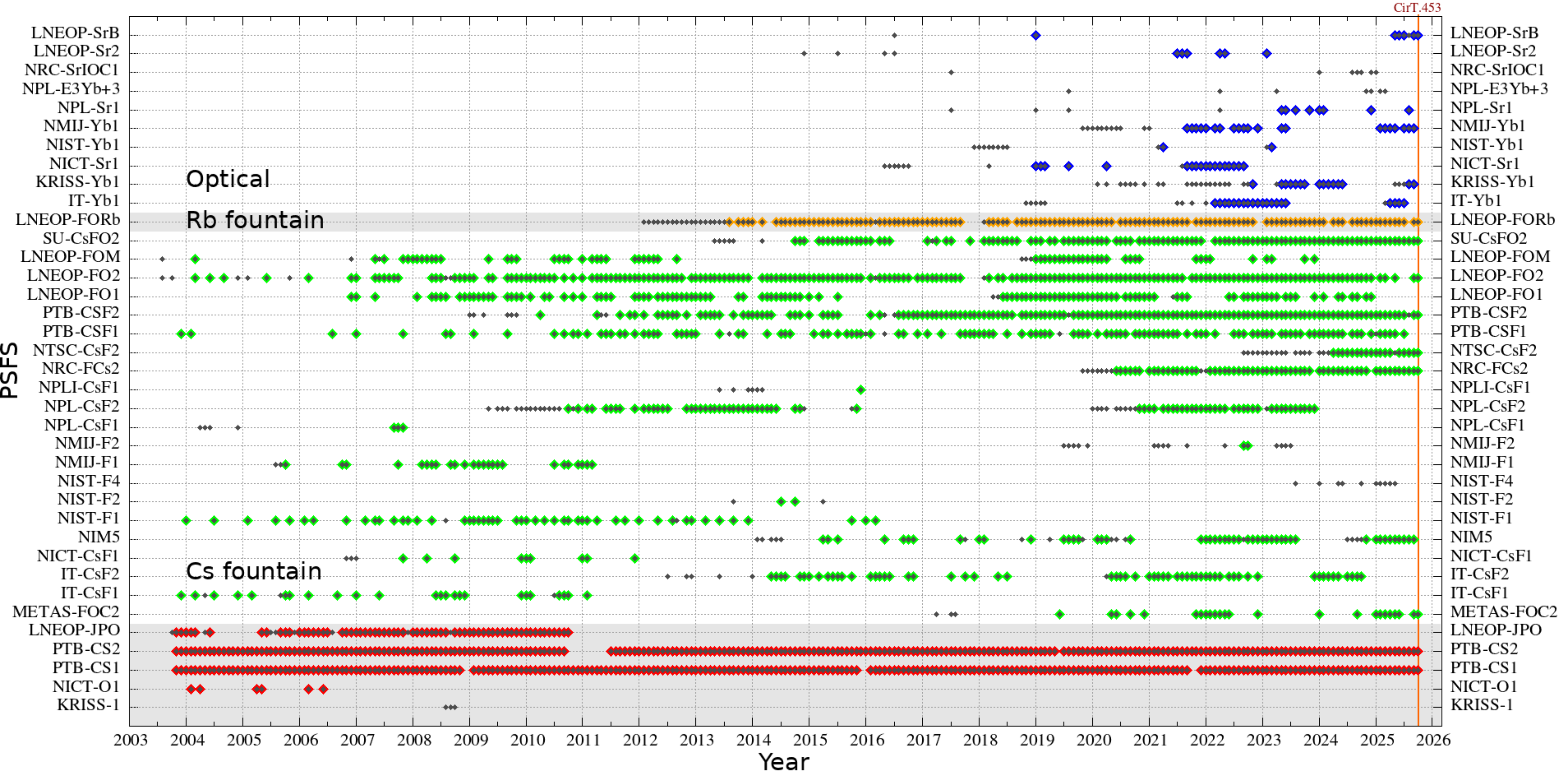
Criterion	Achieved	Criticalities	Proposed mitigation actions
I.1 - OFS accuracy budgets (< $2x10^{-18}$) I.1.a—At least … same referen… institutes, hav… evaluated rel… uncertainties… comprehensi… published acc… I.1.b—At leas… evaluations o… reference tra… same institut… have demons… uncertainties… comprehensi… published acc…	Reagarding 1.1.a, AI+ has two OFSs in difference institutes (NIST and PGMF) with uncertainty below $2x10^{-18}$	Considering I.1a, we have not yet even 1 of the required 3 frequency evaluations of OFS based	Additional frequency evaluations towards an accuracy ≤ 2×10^{-18} are encouraged; in particular for reference transitions where at

Criterion	Achieved	Criticalities	Proposed m… actio…
I.2 - Validation of OFS accuracy budgets Frequency ratios (< $5x10^{-18}$) I.2.a—Unit ratios (frequen… standards with same clock… measurements between O… in agreement with an over… comparison $\Delta\nu/\nu \lesssim 5\times10^{-}$… transportable clocks or adv… to at least one radiation of… I.2.b—Non unit ratios (freq… between standards with di… at least five measurements… among I.1 or other, each ra… twice by different institute…	Considering I.2a, 5 measurements of unit ratios (comparisons between same clock transition) between OFS in the same institute agree to ≤ 5×10^{-18}. [NIST, PTB, LUH RIKEN], 1 NEW ≤ 2.4×10^{-17} [NPL]	Considering I.2a, we have not yet achieved even 1 of the required 3 unit ratio measurements between OFS in agreement between different	More compa… essential (e.g… transportable… the publicati… results is

Criterion	Achieved	Criticalities	
I.4 - Regular contributions of OFS to TAI (3/5 OFS contributing @ $2x10^{-16}$ each month for 1 year) I.4. — At least three state-of-art calibrations of TAI (uncertainty $\lesssim 2\times10^{-16}$ without counting the recommended uncertainty of the…	10 OFS from 8 institutes have performed 182 TAI calibrations to date. [INRIM, KRISS, NICT, NMIJ, NIST, NPL, NRC, SYRTE]	There have not been 3/5 OFS calibrations of TAI every month for 1 year at any uncertainty levels. There also has not been even 1 month with 3 OFS calibrations of TAI with uncertainty $\lesssim 2\times10^{-16}$. Also, contributions have dropped off in 2024.	Er… pe… Er… ca… ef… ov… ac… ur…

Graphical representation of all evaluations of Primary and Secondary Frequency Standards reported since Circular T 190.
Enhanced color dots indicate evaluations carried out within the month of TAI computation.

Neutral+ Ion OFS



Redefinition of the second – Current situation

Huge work has been already done, with significant progress, since the very first version (2016) of the roadmap towards the redefinition → Updated roadmap in 2025 with:

- **Pro & Cons analysis** of the options – Progress in the **maturity of OFS** - **Short list of possibilities** for the new definition
- Progress in the **fulfilment of criteria** (OFS, TF transfer) to ensure the success of the new definition
- The **momentum has been maintained** thanks to engagement of the CCTF Task Force, its subgroups and the involved NMIs,

but

- **a consensus has not yet been reached** either between the choice of a single species and an ensemble of species for the new definition, nor on the choice of the preferred species themselves, despite active scientific debate,
- **noticeable inconsistencies in some comparisons** of optical frequency standards and in a part of the frequency ratio measurements have been observed during recent comparison campaigns,
- **some criteria are far from being fulfilled**, for instance a comparison uncertainty below 5E-18 which has not yet been achieved between clocks of the same type developed by different laboratories, or the regular contribution of OFS to the calibration of TAI with the adequate uncertainty level,

→ It is not possible to take a major decision at the CGPM in 2026…
… but it is realistic to maintain the target date for a decision on the redefinition in 2030

Proposed draft CGPM Resolution on the redefinition of the second

The CGPM, at its 28th meeting,

→ **Requests the CIPM:**

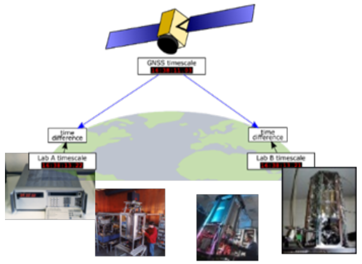
- to continue to promote the importance of achieving the objectives agreed in the roadmap for the definition of the second and achieving consensus on the option for redefinition,
- to work towards a proposal for the new definition of the second to be presented at the 29th meeting of the CGPM (2030) and a proposal for the date of its implementation.

→ **Invites the Member States** to support activities aimed at fulfilling the mandatory criteria, with the provision of human and financial resources needed to ensure the improved realization and dissemination of the unit of time and of time scales.

Continuous UTC

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

the Coordinated Universal Time UTC



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

≈ 450 atomic clocks
≈ 10 primary frequency standards

in ~ 85 laboratories

TAI

International Atomic Time

Measurement of Earth's rotation UT1 (IERS)

leap seconds

UTC

Coordinated Universal Time
|UT1 – UTC| < 1 s

UTC is the international reference time scale,

computed and distributed by the Bureau International des Poids et Mesures (BIPM) in Sevres, France,

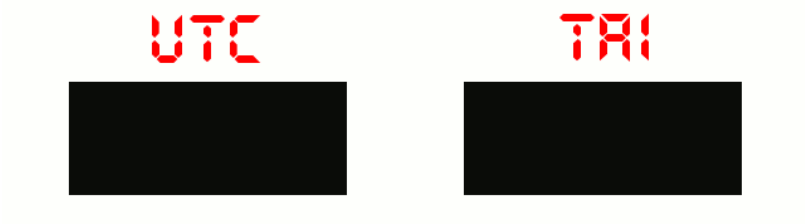
based on the readings of about 450 high performance atomic clocks kept all over the world by 85 timekeeping laboratories

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

The Coordinated Universal Time UTC is kept in agreement, within 1 second, with the rotational angle of the Earth UT1

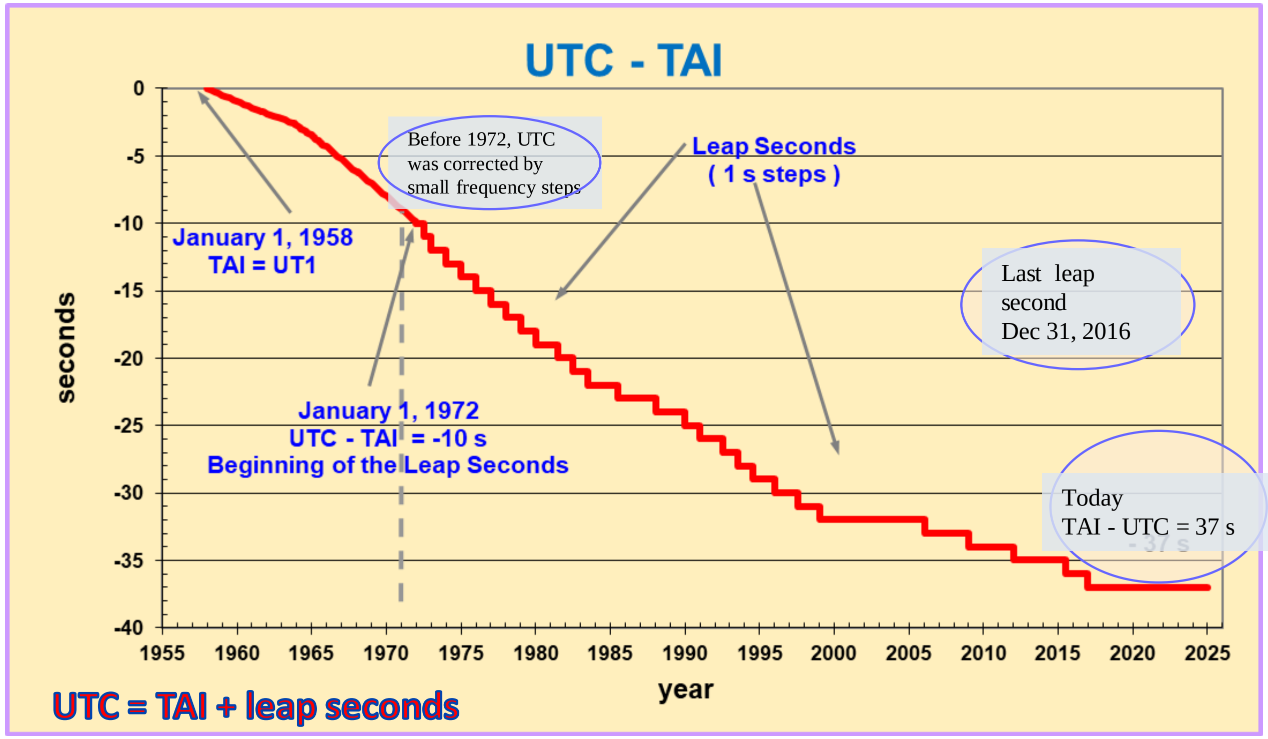
Timekeeping is based on atomic clocks forming the International Atomic Time- TAI. UTC is obtained from TAI by adding/removing integer seconds

When the difference between the Earth rotational angle UT1 time scale and UTC reaches 0.9 second, an integer second is inserted to UTC to keep it within 1 s of UT1.



|UTC - UT1| < 1 second

UTC = TAI + n seconds



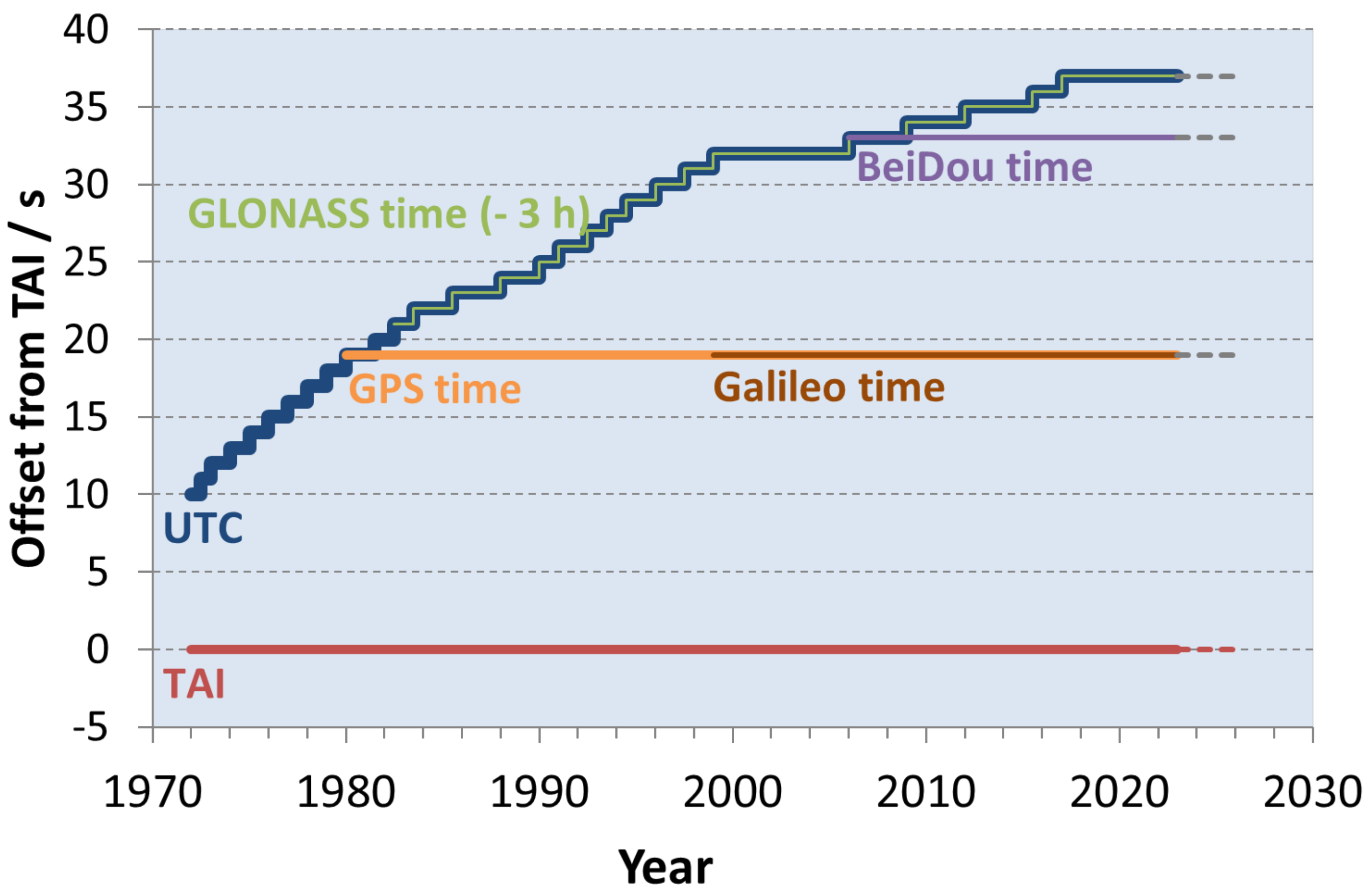
In the '70s UTC was used as approximation to UT1 mostly for navigation with traditional optical instruments.
The approximation UTC ≈ UT1, at 1 second tolerance, corresponds to an uncertainty in the position up to 400 m (at the equator).

Nowadays IERS and NASA estimate UT1 with 10 microsecond uncertainty corresponding to about 0.3 cm uncertainty in the position

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

Global Navigation Satellite System (GNSS) need a continuous time scale

GNSSs prefer a continuous time scale and do not add leap seconds on their GNSS time scale (except GLONASS which applies leap seconds). These time scales are easily available all over the world, are commonly used as time and frequency references, and differ from each other and from UTC by several seconds.



The digital networks cannot cope with unpredictable leap seconds

Consultative Committee on Time and Frequency User Survey (2021)

- \> 200 answers
- The users asks to get rid of discontinuities in UTC

WIRED — The Inside Story of the Extra Second That Crashed the W

BUSINESS | CULTURE | GEAR | IDEAS | SCIENCE

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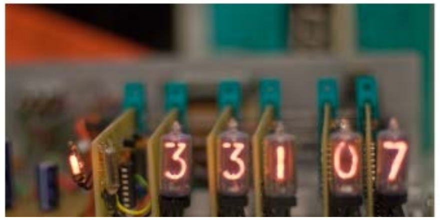
ROBERT MCMILLAN AND CADE METZ | BUSINESS 07.02.12 07:54 PM

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

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

NETWORKWORLD FROM IDG

IDG TECH(Talk) | IoT | 2-minute Linux tips | Newsletters | Resources/White Papers

'Leap second' snafu affects Oracle clusterware

By Chris Kanaracus

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

DIGITAL MAGAZINE | EVENTS & AWARDS PROGRAMS | VIDEO

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

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

Time travels on the network

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

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

CGPM

Resolution 4

"On the use and future development of UTC"

Working together to promote and advance the global comparability of measurements

November 2022

https://www.bipm.org/en/cgpm-2022/resolution-4

CGPM 2022 Resolution 4 - On the use and future development of Universal Coordinated Time (UTC)

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

When?

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),
- propose a time period for the review by the CGPM of the new maximum value following its implementation, so that it can maintain control on the applicability and acceptability of the value implemented,
- draft a resolution including these proposals for agreement at the 28th meeting of the CGPM (2026),

What?

Decision at the CGPM in October 2026

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.

Continuous UTC: outcome from ITU WRC 2023

After 3 weeks of negotiation…

ENDORSED by

Thanks to All, a great example of collaborative effort towards an international agreement

WRC Rec 655 states:

- CGPM is responsible for UTC definition and rules.
    - Res 4 of CGPM 2022 has decided that the offset UT1-UTC will be extended in, or before, 2035.
- ITU is responsible for the broadcast of UTC
    - ITU-R Rec 460, containing the code for broadcasting UT1-UTC by radio emitting stations, has to be updated with UT1-UTC > 1s.
- BIPM and ITU work together with the common goal of realizing and distributions to the users the most adapted and useful international time scale. To this aim, BIPM and ITU signed a memorandum of understanding in 2020 and will continue a close collaboration.

ITU WRC 2023 preferences:

- > 100 s tolerance
- application possibly in 2035
- possibility of more time, till 2040, to update the radio stations broadcasting the value UT1-UTC

Drivers in the discussion on continuous UTC

We want to make UTC

- The only international time scale universally accepted and used.
- Supporting the needs of industries and users
- With a known and disseminated offset versus UT1
- With a possibility of adjustment in the future the less impacting as possible.

Main synchronization needs in telecom, energy distribution, finance, transports, and space users need

- a continuous time scale

Today several are based on GPS time

INTERNATIONAL TELECOMMUNICATION UNION

TELECOMMUNICATION STANDARDIZATION SECTOR

STUDY PERIOD 2017-2020

SG15-TD780/PLEN

STUDY GROUP 15

Original: English

Question(s): 10, 11, 12, 13, 14/15 — E-Meeting, 6-17 December 2021

TD

Source: Chairman WP3/15

Title: WP3 liaison statements

Purpose: Admin

…continuous time without leap seconds traceable to common time reference…

Given the 3GPP requirement for a continuous timescale, the actual implementation in this case could make use of the content of the distributed UTC information that is not impacted by leap seconds, e.g., GPS time…..

In conclusion, defining for the future a continuous UTC without additional leap seconds (or where periodical adjustments are performed over periods sufficiently long to not impact the operation in the network) can be considered beneficial in the telecommunication context as it could simplify related specifications and reduce risks on some implementations

A CCTF Task Group is working to prepare the draft resolution for the *Conference General Poids et Mesures* - CGPM 2026

What?

• *extended tolerance value of UT1-UTC*

- industrial users and synchronization needs of national critical infrastructures such as transportation, energy distribution, and telecommunication require UTC to be continuous **without any future adjustment**,
- for some applications it is necessary **to fix a maximum limit** for the difference |UT1-UTC| to design codes to disseminate this quantity

2 options:

- ± 100 seconds (or 5 min) => continuity about one century
- ± 1 hour (daylight saving time/ time zone) similar as No limit => continuity about one millennium

Social perception of astronomical conformity

Civil and legal time is worldwide related to the Coordinated Universal Time (UTC), while the mean solar time is related to the Earth’s rotation as quantified by the angle measurement UT1;

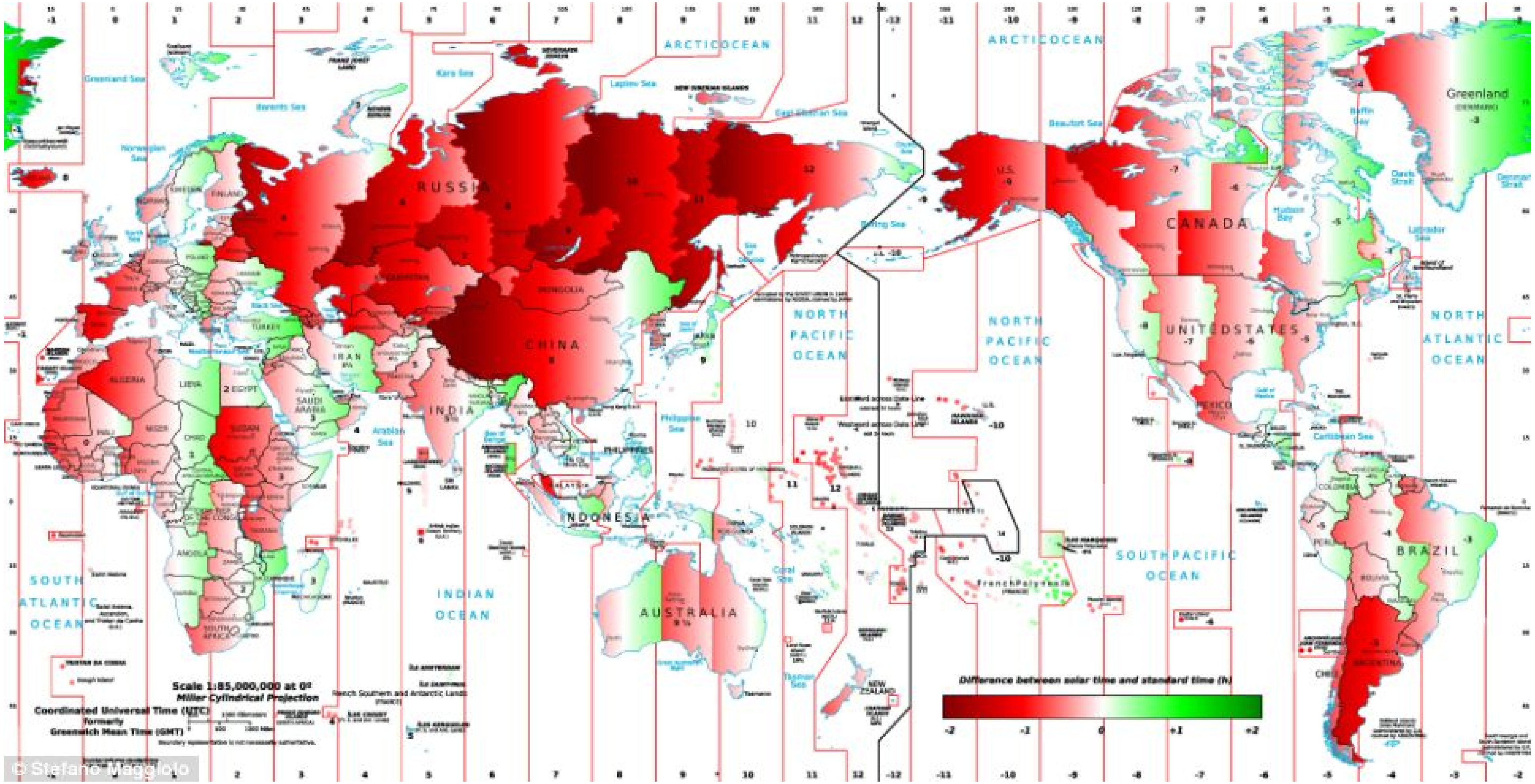
- we want to maintain a well known and limited allowed difference between solar and civil time

- the difference between apparent solar time and mean solar time called the “equation of time” can vary by as much as ±900 seconds during the year,

- legal civil time is based on time zone and may even encompass more than one time zone causing large differences, up to ±2 hours, between local apparent solar time and legal time,

- the activation of daylight-saving time in some countries introduces a one-hour discontinuous change in legal civil time, and a corresponding change in the difference between civil time and apparent solar time

Difference between solar and civil time



https://www.dailymail.co.uk/sciencetech/article-2572317/Are-YOU-living-sync-Amazing-map-reveals-manmade-timezones-countries-false-sense-sun-rises.html

One hour is still acceptable

A CCTF Task Group is working to prepare the draft resolution for the *Conference General Poids et Mesures* - CGPM 2026

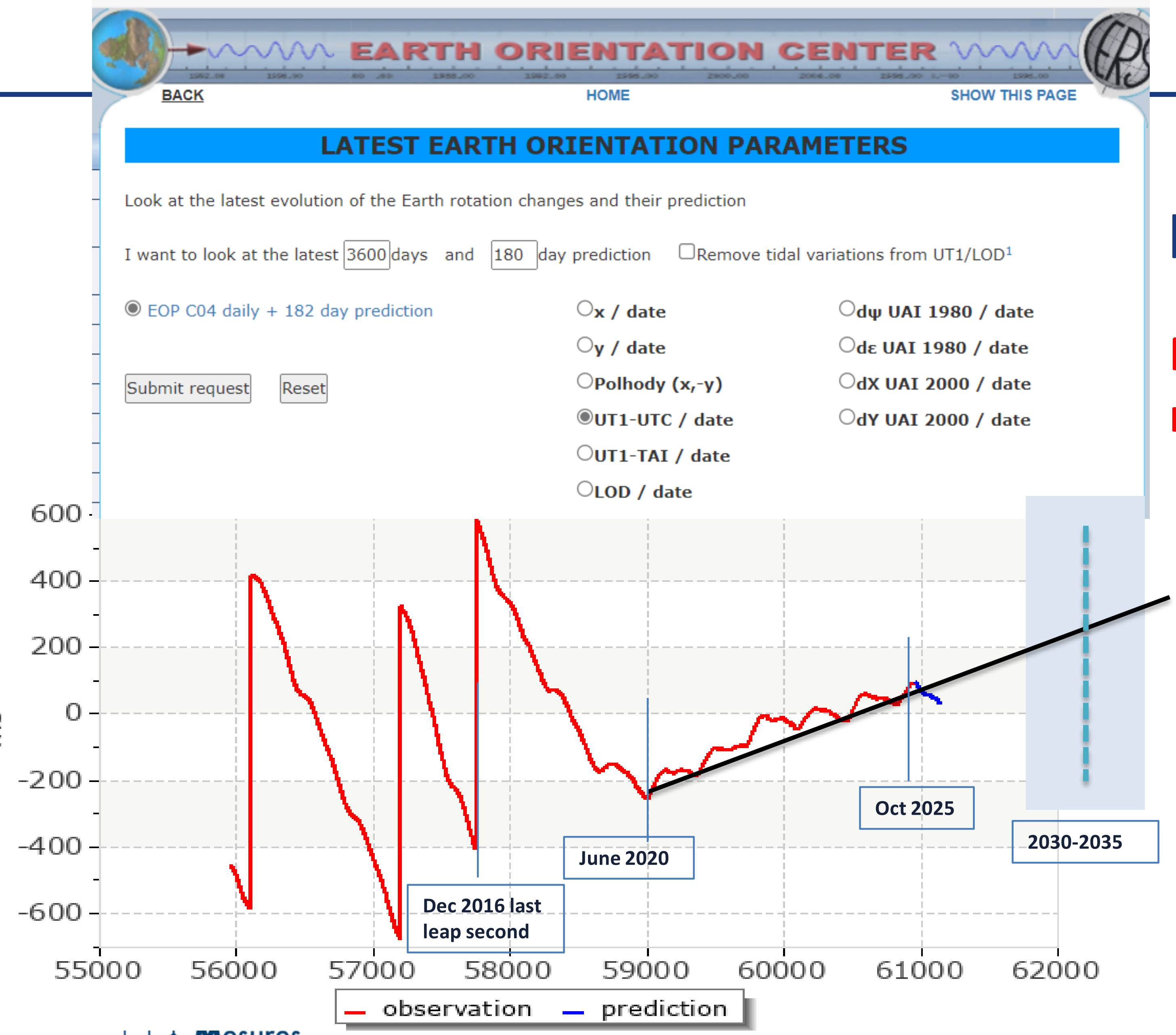
1) **Provide the value of the new limit for UTC-UT1 to ensure a continuous UTC at least over one century**
   2 options:
   ~~- 100 seconds (or 5 min) => continuity about one century~~
   - 1 hour (can be applied as daylight saving time/ time zone change) and it similar to No limit => continuity about one millennium

2) **Provide the date of implementation (in or before 2035) :**
   Some countries recommend 2035 to update technological systems, other countries and user communities are urging the change to avoid any disruption

   Ready for a negative leap second?

When?

CGPM 2022 says *in, or before, 2035*



Is the Earth deciding for us?

Possibility for the first negative leap second ?

≈200 ms/3 years

Reaching 600 ms in 10 years?

https://eoc.obspm.fr/index.php?index=realtime&lang=en

A negative leap second coming soon?

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.

An important risk of a negative leap second could definitely push towards a quicker change in UTC

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/

almost as likely as not to experience a negative leap second in the next 12 years

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

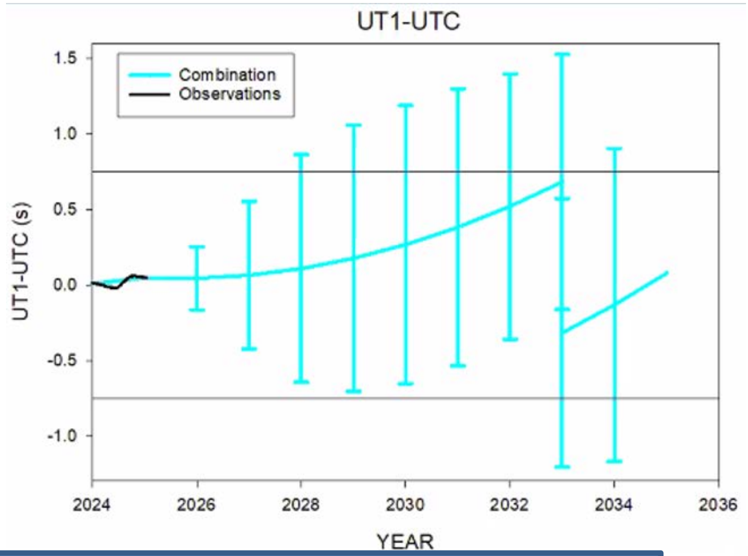
Join BIPM-IERS workshop on Earth rotation modelling (March 2025)

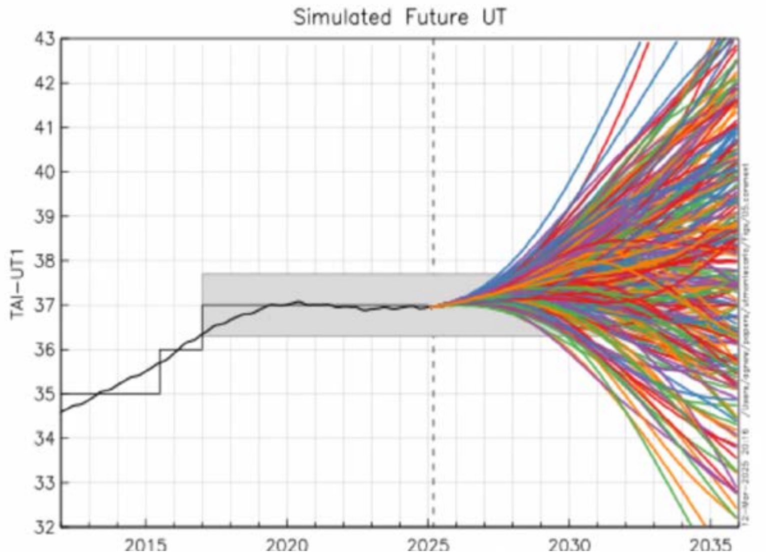
→ Gathering experts of Earth rotation modelling to evaluate a probability range for a negative leap second

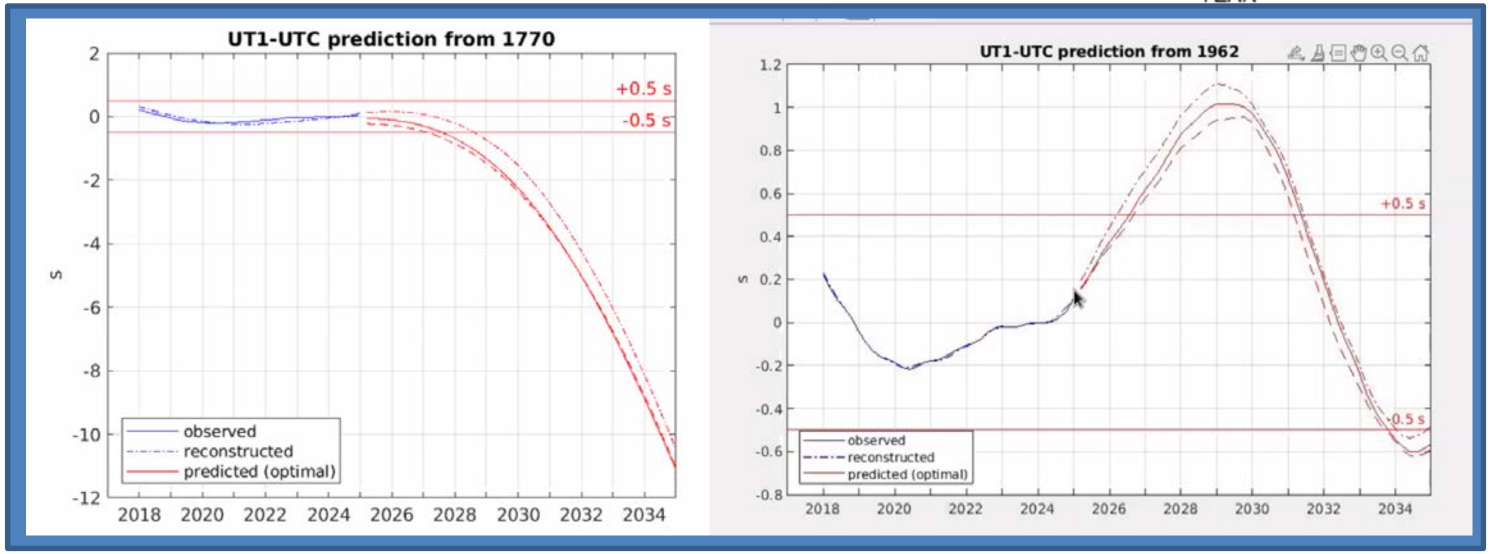
Each model takes into account one or a few effects (no « global » model) :

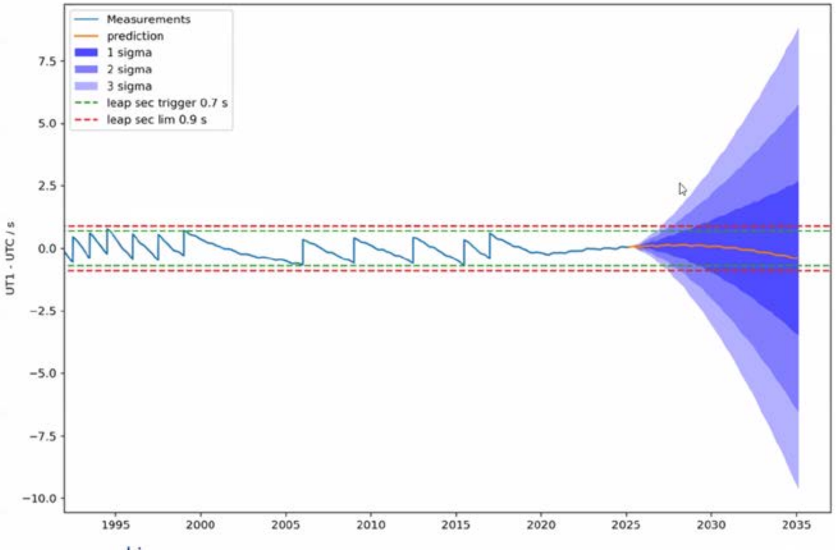
- Global mean sea level
- Core-mantle interaction
- Glacial isostatic adjustment
- Tidal friction
- Moment of inertia
- Atmospheric and oceanic effects
- Climate processes

\+ Purely statistical prediction









Join BIPM-IERS workshop on Earth rotation modelling (March 2025)

→ **Gathering experts of Earth rotation mode[…]uate a probability range for a negative leap second**

Each model takes into account o[…] effects (no « gl[…] » model) :

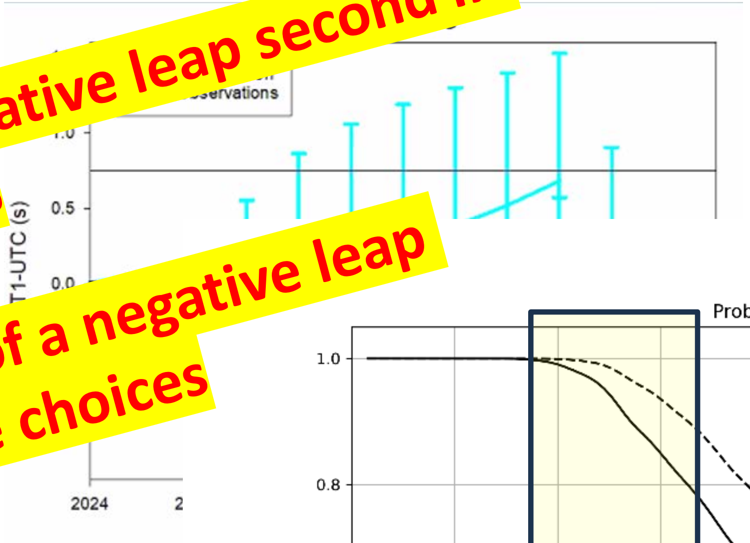
- Global mean sea level
- Core-mantl[…]
- […]
- […]
- […]
- A[…] effects
- Cli[…]ses

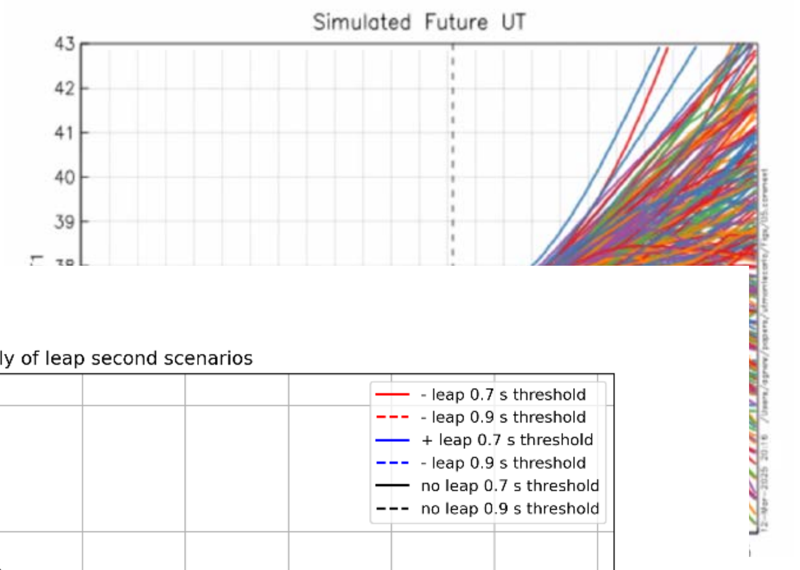
\+ Purely statistical predi[…]

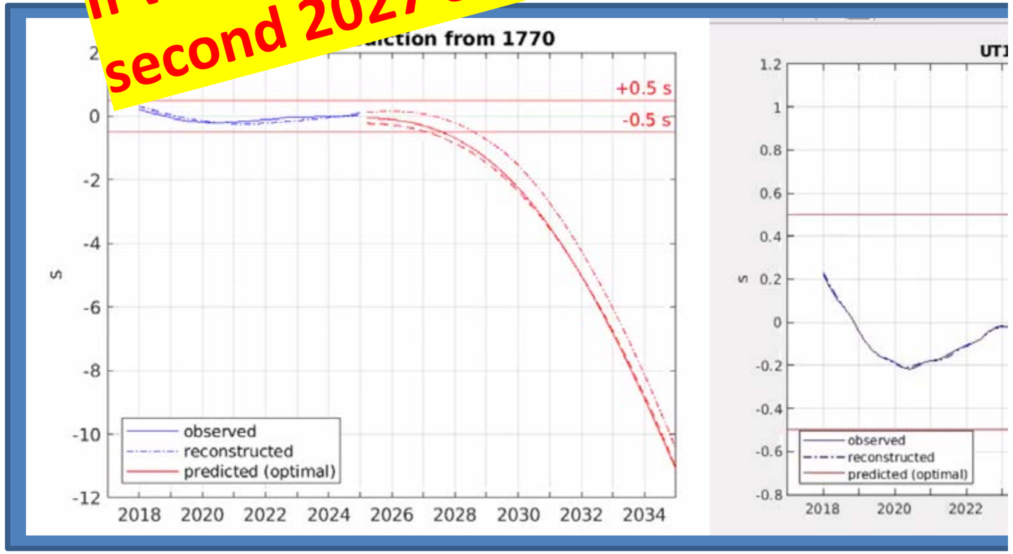
Starting from different expertise and point of view, it has been estimated that

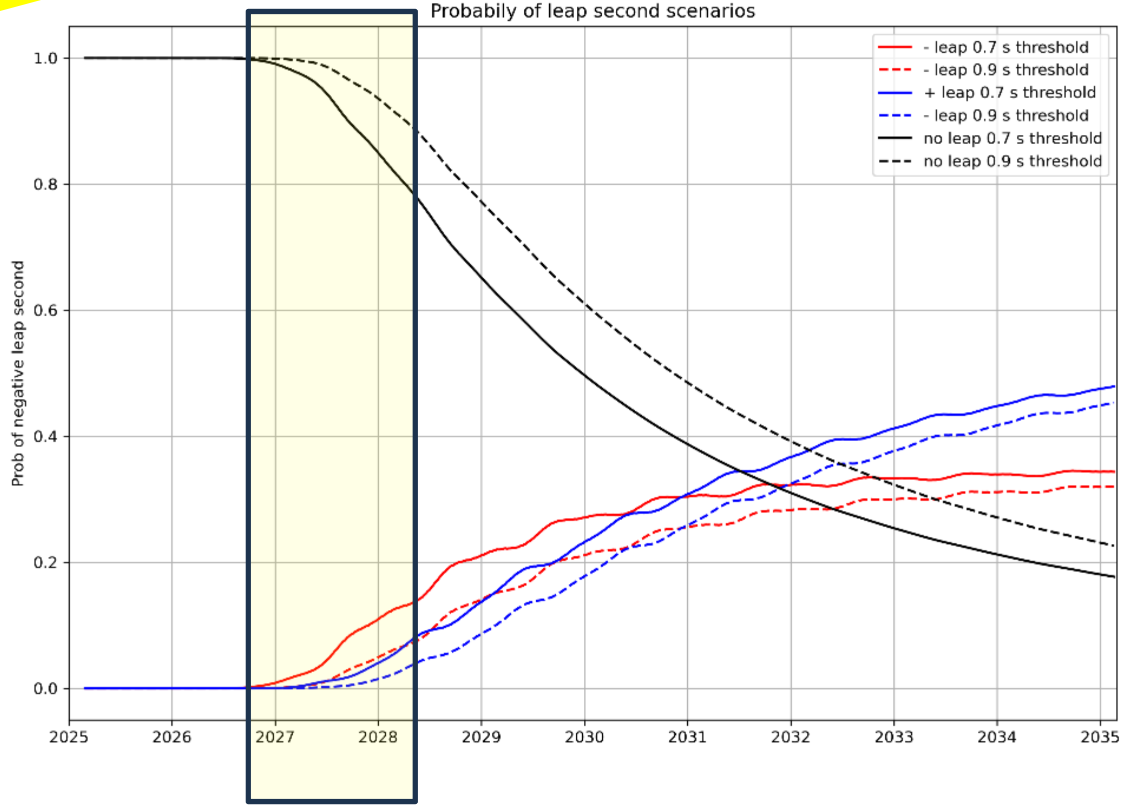
The probability of having a negative leap second in the next 10 years is about 30%

If we want to avoid the risk of a negative leap second 2027 or 2028 are the choices









Workshop on negative leap second: following actions

The BIPM IERS workshop concluded that there is a probability of

When?

- 25-30% of a negative leap second before 2035
- similar, slightly higher, probability of positive leap second

1. Which is the impact of a negative leap second on
   - Telecom
   - Energy distribution
   - Transport
   - Finance
   - Space activities
   - …

2. Commercial equipment can handle (negative) leap seconds?
   - Contact industrial groups

3. Which is the resilience of national critical infrastructures to
   - 10% probability of a negative leap ?
   - 20% probability ?
   - 30% probability ?

RMO TCTF Chairs asked to the users in their countries

URSI representative discussed at URSI GASS 2025

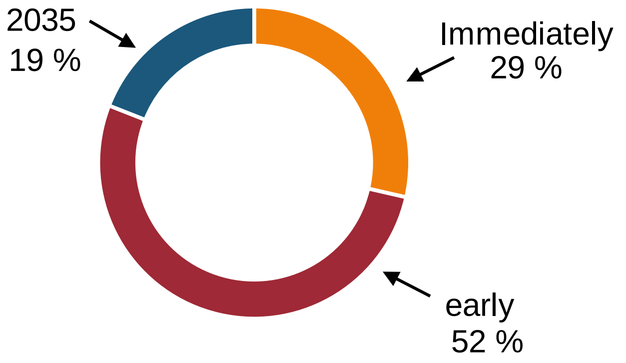
ITU representatives where contacted. ITU-T send a liaison statement

Industrial fora informed and formal feedback received as IEEE 1158 plus several company statements

IERS sent a formal statement

APMP

- negative leap second would have impacts on a wide range of industries (*Telecom, Energy distribution, Transport, Finance, AI, Cloud Services, distributed networks, Space activities, GNSS….*).
- Equipment that is more than 10 years old or low-end equipment may not be able to cope.



Timing of implementation of the new tolerance values

AFRIMET

in favour of either completely removing leap seconds, or increasing the tolerance with no conditions. None were expressing any opposition against an earlier implementation date.

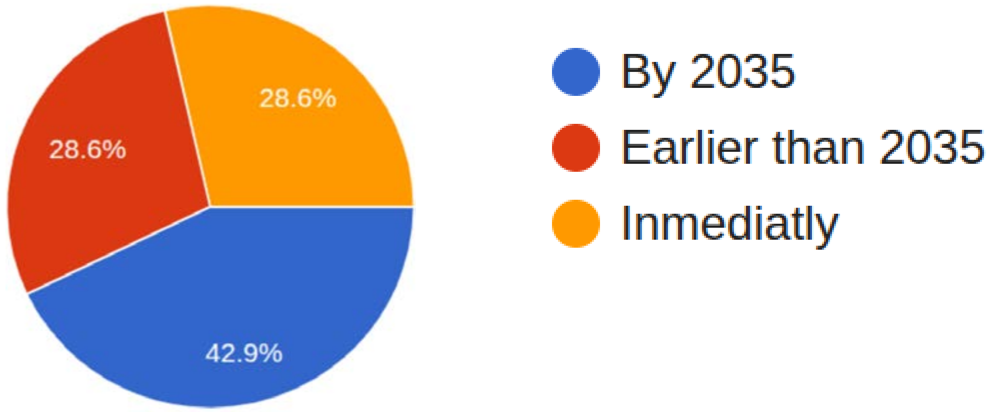
EURAMET

There is no evidence that commercial equipment is fully prepared for a negative leap second,
National critical infrastructures are largely unprepared for a negative leap second due to a lack of real-world testing, outdated equipment, and high uncertainty about system behavior.

- Implementation date: the sooner the better to avoid unnecessary risk – 2027 or 2028

SIM

tolerance must be extended as quick as possible. Delaying the decision may discourage the use of UTC as a time reference.
The risk for critical infrastructure, sectors and industries is high. Also, this creates a barrier for the adoption of UTC as a universal time standard



COOMET

negative leap second could cause disruptions in systems with tight time synchronization, particularly in industries such as manufacturing, telecommunications, transportation, finance, and energy supply

Russian Federation:
We share the concerns of our colleagues regarding the possible negative impact of a negative leap second on the work of telecom operators, transport, the financial sector, energy and other industries. We are also concerned that a negative leap second has not been introduced before, and the stability of technical systems when it is introduced has never been confirmed in practice. The final position of the Russian Federation on this issue will be formed after consultations with representatives of interested ministries and departments

Feedback from ITU-T

SG15Q 13 dealing with synchronization

sent a liaison statement on June 26, 2025

INTERNATIONAL TELECOMMUNICATION UNION
TELECOMMUNICATION STANDARDIZATION SECTOR
STUDY PERIOD 2025-2028

SG15-LS45
STUDY GROUP 15
Original: English

Question(s):	13/15	Paris, 9-13 June 2025

(**Ref. :** SG15-TD96/WP3)

Source:	ITU-T SG15
Title:	LS/r on the possibility of a negative leap second and request of information on its impact in ITU-T (reply to BIPM-LS2)

LIAISON STATEMENT

For action to:	
For information to:	BIPM, IEEE PNCS (P1588 WG)
Approval:	Q13/15 meeting (Paris, 13 June 2025)
Deadline:	-

Contact:	Stefano Ruffini Rapporteur Q13/15	E-mail: Stefano.ruffini@calnexsol.com
Contact:	Lee Cosart Associate Rapporteur Q13/15	Email: lee.cosart@microchip.com

Abstract: This liaison deals with information on the possibility of a negative leap second.

Q13/15 thanks **BIPM** for the liaison "*Information on the possibility of a negative leap second and request of information on its impact in ITU-T*" (**TD94/3**). This was reviewed by the group at this meeting.

The group discussed the question related to resiliency and the potential impact of a negative leap second (with about a 30% probability of happening in the next 10 years). Some concerns have been expressed on this risk. This is an event that most likely has not been fully tested across all implementations, and recent test activities were mentioned, which showed with high probability that legacy systems would not handle negative leap seconds properly. A minimal probability that a leap second could occur in the near future will likely lead to large investments for the industry in order to reduce the impact on critical infrastructure such as mobile networks (where time synchronization is a prerequisite for the network to operate) or power networks. Investments required by "Year 2000" related projects, may provide some reference on the potential cost impacts.

As a result, Q13/15 recommends that the increased tolerance between UTC and UT1 (in that case future corrections of UTC are not expected to happen in the near future, i.e., for a hundred years or more) is implemented as soon as possible to remove any risk of the occurrence of a negative leap second, especially given the relatively short advance notification time (6 months). It is also worth highlighting that telecom applications typically require continuous timescale (see Appendix VI in ITU-T Rec. G.8271), and there is no need to know the UTC-UT1 difference.

During the discussion it was also noted that definition of new solutions to keep UTC close to UT1 involving changing frequency (and the duration of the second) could have a large impact on existing systems and timing protocol, and corrections with an integer number of seconds should be considered instead.

ITU-T SG15 looks forward to further cooperation with BIPM and IEEE P1588.

International Earth Rotation
and
Reference Systems Service
(IERS)

Prof. Adrian Jäggi
(Chair)
Dr. Robert Heinkelmann
(Analysis Coordinator)
Dr. Daniela Thaller
(Director Central Bureau)

Dr. Patrizia Tavella
Director of Time Department
BIPM
Pavillon de Breteuil
F-92312 Sèvres Cedex
France

2025-09-01

IERS feedback to CCTF

Dear Dr. Tavella,

From IERS point of view we do not see any advantage of having a 100 s or 120 s limit over the 3600 s limit. The difference of mean and apparent solar time, equation of time, alone is already +/- 900 s about. The extension of the individual time zones are the next fact that creates an effective difference of Sun's culmination moment and midday of zonal time. On top we have the activation and deactivation of daylight saving time in several countries. Users that need a precise solar time will use UT1, not UTC, regardless of its limit with respect to UTC. It causes the same amount of work for adaptation. But instead, choosing 100 s or 120 s might require again an adaptation in a relative short while; eventually even earlier than anticipated. Revising the limit again in a few decades could be seen as not serious / not reliable and would again cause work for the transition. Concluding for IERS, there is no advantage for the more restrictive limit.

On the other side, considering (i) the potential risks for society facing leap second insertion and in particular a potential negative one and (ii) the efforts of all the bodies involved in the creation of this resolution and the subsequent adaptation of all procedures, the IERS suggests to go for 3600 s and not less.

Hence, the IERS supports the adaptation of a leap hour between UT1 and UTC instead of the current leap second.

Concerning the date of implementation, considering the risks, the IERS agrees with the proposal of advancing the application date to 2027-2028.

The IERS does not see the necessity of recommending revisiting this decision as part of the text of the resolution. All scientific resolutions are binding. But of course, if deemed necessary, they can be altered or updated.

Once a new process has been adopted for the UT1 – UTC relation, the IERS will take all necessary measures to change its operational provision of and its announcement of leap seconds accordingly.

With best regards,

Dr. Robert Heinkelmann
IERS Analysis Coordinator, on behalf of IERS

Extended value of UT1-UTC: how will it be disseminated?

When UT1-UTC is larger than 1 second, it will be very important to disseminate this value to all the users with reliability, accuracy, robustness, large availability and coverage
Are the dissemination services ready?

When?

✓ GNSS

- GPS can accept ± 63 s (modernized one should be ±127 s, already implemented in some satellites)
- GLONASS has been modernized to accept ± 255 s *(11/24 satellites)*
- Beidou can accept ± 63 s
- Galileo is not transmitting UT1-UTC
- Also regional navigation systems are available: QZSS ± 63 s

GNSS are surely updated before these limits are reached.
An information document has been sent to the United Nation International Committee on GNSS (ICG) in June 2025.
Presentation of this topic planned at the ICG meeting in Oct 2025

✓ Internet services

- IERS *https://datacenter.iers.org/data/latestVersion/bulletinA.txt*
- NASA *https://cddis.nasa.gov/Data_and_Derived_Products/Other_products/IERS_EOPs.html*
- VNIIFTRI *https://www.vniiftri.ru/en/about/departments/research-department-main-metrological-center-of-the-state-service-of-time-frequency-and-determinatio/*
- NIST and other NMIs publish DUT1 in a paper bulletin and on the internet (from IERS)

✓ Industrial products

companies producing time and synchronization equipment that are evaluating

- *Disseminating the value of UT1-UTC*

Extended value of UT1-UTC: how will it be disseminated?

When?

When UT1-UTC is larger than 1 second, it will be very important to disseminate this value to all the users with reliability, accuracy, robustness, large availability and coverage

Are the dissemination services ready?

Radio stations (regulated by ITU-R Rec 460)

	Station	Country	DUT1 transmission
1.	ALS 19, ANFR	France,	NO
2.	BPC BPL BPM, NTSC	China,	NO
3.	CHU	Canada	YES stop transmission of DUT1
4.	DCF 77	Germany	NO
5.	HLA	Korea	NO
6.	JJY (2 stations)	Japan	NO
7.	LOL	Argentina	YES stop transmission of DUT1
8.	Mikes	Finland	NO
9.	MSF	UK	YES propose stopping DUT1
	Other 3 stations	UK	NO
10.	RAB…RWM (9 stations)	Russia	3 stations transmits DUT1 update with ITU-R solution
11.	WWV WWVB WWVH	USA	YES stop transmission of DUT1

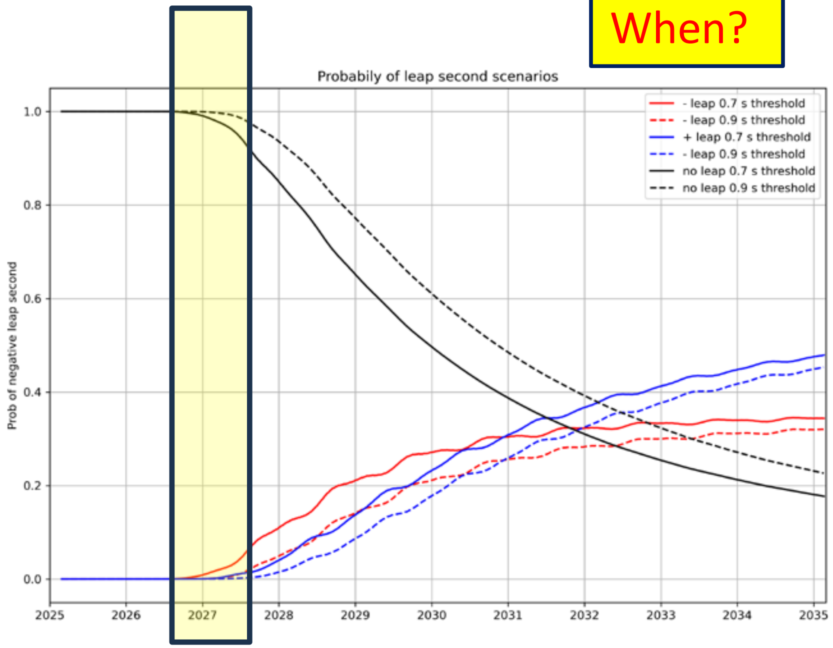
11 countries have radio stations in operations yet,
Only 5 transmit DUT1 = UT1-UTC
All plans to stop this service, only Russia plans to maintain it on 3 radio stations that will be updated accordingly to the ITU R code update (in progress)

Which is the expected evolution of the radio station signals?
ITU WRC 2023 Rec 655 allows till 2040 to update the implementation of the updated DUT1 code

Only 3 VNIIFTRI Radio Stations will continue to transmit UT1-UTC with updated code (with the support of electronic or paper bulletins).

summary: date of implementation *"in or before 2035"* (CGPM 2022)

When?



1. The probability, even minimal, of a negative leap second in the next 10 years is considered a high risk of anomalies and disruption by most industries. Small inconsistencies can lead to major failure. High uncertainty and potential disruptive challenge. National critical infrastructures largely unprepared.

2. Someone reported possibly no issues, but nobody feels completely comfortable. Legacy instruments can be an issue. NMIs are expected to have no issues.

3. ITU–T, IEEE1588, and industries asks to act "as soon as possible" to remove any risk of negative leap second by formal statements

4. Large burden for preliminary measures. Comprehensive tests not possible. Preventive actions would cost hundreds of billions. Leap second have only 6 month notice.

5. The users of UT1 will find UT1-UTC information in GNSS, Internet services. ITU-R WP7A is progressing towards a solution for the radio stations code. Most of stations will stop DUT1 transmission.

Proposal:
Advance the application date to 2027 (or 2028) as the large majority of users see the negative leap second as an unacceptable risk.

The CIPM in the meeting in June considered high risk of

- UTC and NMI work is not used, TAI or GPStime will be recommended, if we allow a negative leap second
- It is the duty of NMIs to support the national industries and stakeholder

Proposed draft CGPM Resolution on continuous UTC

The CGPM 2026, at its 28th meeting,

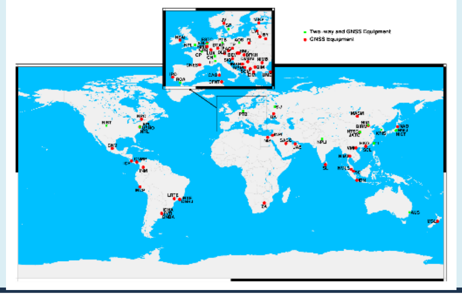
decides that
- continuous UTC will become effective on **May 20 2027** (*or 2028 to be decided in Jan 2026)*
- the maximum value for the difference |UT1-UTC| will be **3600 seconds** (1 hour), ensuring the long-term continuity for UTC for several centuries

requests the BIPM
to continue to work together with the ITU, International Astronomical Union, International Union of Geodesy and Geophysics, IERS, and other organizations that may be impacted by this decision in order to
  - inform users and support the application of this decision
  - continue to monitor the value of UT1-UTC, its estimated evolution and modelling as determined by IERS
  - inform the CIPM regularly on the evolution of the value of UT1-UTC.

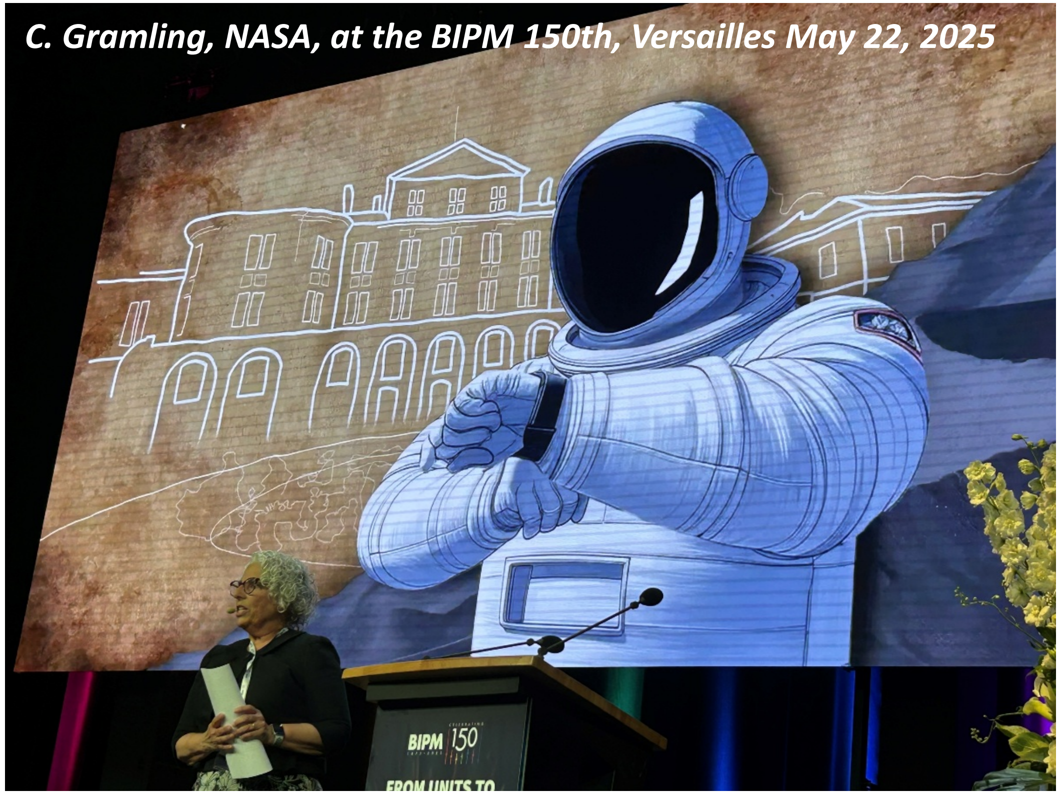
Please discuss with your timing experts and support

promote opportunities in your countries to inform on the challenge of a negative leap second

to ensure UTC addresses all user needs



Lunar reference time



C. Gramling, NASA, at the BIPM 150th, Versailles May 22, 2025

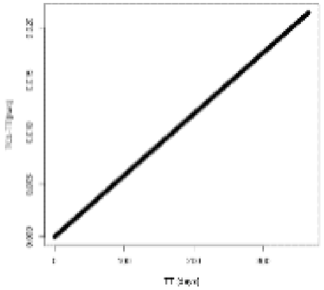
Context - Numerous projects for Moon exploration

Several **Moon programs** including Lunar Communication and Navigation Services with GNSS-like **Positioning Navigation and Timing** (PNT)

Proliferation of time scales should be avoided, to limit the risk of ambiguity when exchanging time-tagged data, so there is a need to:
- **Fix the spatio-temporal reference systems for interoperability**, and especially the reference time scale for Moon operations
- **Ensure the traceability to UTC** for the Lunar reference time
- Extension to **Mars** and other planets

Requirements on the **accuracy of future Moon PNT will not allow the direct use of UTC**, due to the important time difference between a clock on the Lunar geoid and a clock on the Earth geoid

Time drift
(56 µs/day)



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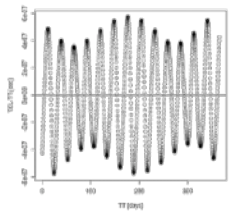


Periodic terms
(amplitude about 0.6 µs)

Decisions on reference systems involve multiple actors

IAU International Astronomical Union

IUGG/IAG Int Union of Geophysics and Geodesy

ITU International Telecommunication Union

ICG United Nations Int Committee on GNSS

Interagency Operations Advisory Group

Bureau International des Poids et Mesures

Recent steps forward

IAU General Assembly 2024 resolutions

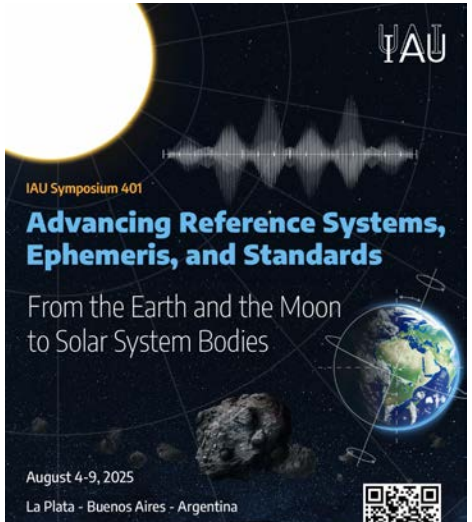
- **Resolution II**: defines the theoretical framework for 4D Lunar Celestial Reference System (LCRS), with the Lunar Coordinate Time TCL
- **Resolution III**: Encourages the establishment of a lunar reference time scale by international agreement

  Considers *that* ***UTC, as established by the 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.*

IAU Symposium 401 (August 2025, La Plata)

- **Presentations and round table on standards**



Recent steps forward

Joint IAG-IAU Working Group 1.1.3 devoted to Lunar reference frames to work towards:

- The connection between Celestial, Earth and Lunar Reference Frames for the future missions

- The definition, the realization, and the dissemination of Lunar Reference Systems, across agencies and user communities.

Recent steps forward

Working Group-L on Lunar PNT created in Oct. 2024 to work together with other ICG Working Groups and with external international organizations, such as the BIPM, for the identification of appropriate timing systems and the support to the standardization of lunar time with traceability to UTC.

Organization with IOAG of

- 1st ICG-IOAG Workshop in Feb. 2025, Vienna
- 2nd Workshop in Feb. 2026, Vienna

→ **Organization of the Lunar timing session with the BIPM**

Recent steps forward

BIPM CCTF

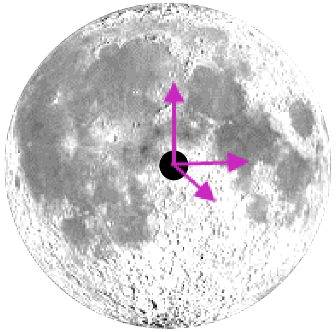
→ **CCTF - BIPM asked by space agencies, IAU, and ICG to contribute to the definition of Lunar reference frame and timing standards**

→ **Recommendation at the 24th CCTF-Session 1 meeting (Nov. 2024):** On the development of a common Lunar reference time scale and its traceability to UTC

→ **A CCTF task group has been formed with NMIs / laboratories of all countries connected to Moon projects + exchanges with the experts in General Relativity and space agencies:**

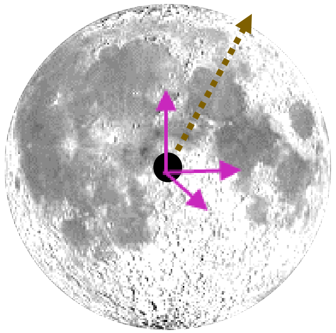
- Extensive study of the proper time variations along the surface of the Moon
- Understanding and clarification of the possible options for a reference time on the Moon and its realization based on UTC timekeeping experience
- Pros & Cons of the possible options
- Identification (with space agencies) of possible operational constraints
- Methodology to have traceability to UTC with uncertainty evaluation

3 options for the Lunar reference time TL



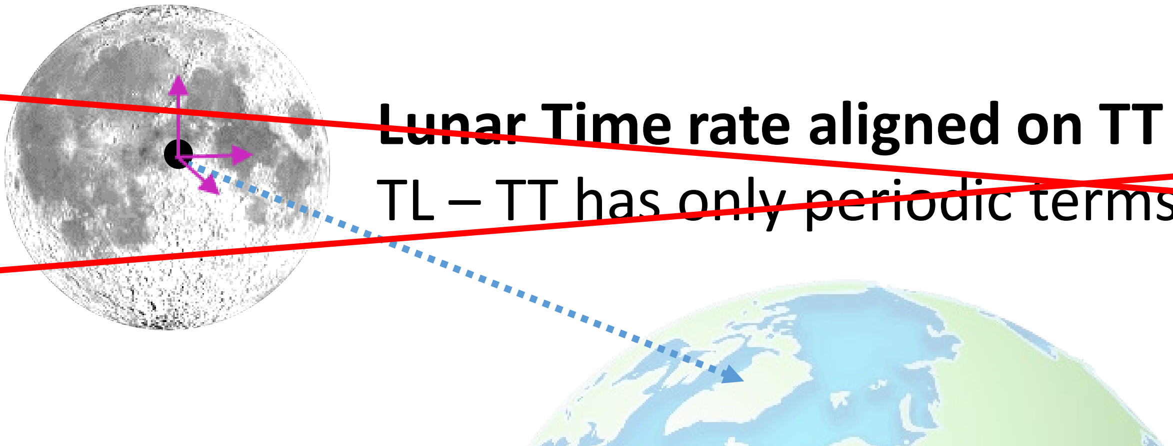
Lunar Time defined at the center of the Moon
TL time scale of the LCRS (Lunar Celestial Reference System)

Do not lead to a new scaling of masses and distances for bodies in the solar system



Lunar Time defined at a fixed gravitational potential (close to the Moon surface)
TL ~ rate proper time of a perfect clock on the surface of the Moon

Would lead to a new scaling of masses and distances for bodies in the solar system



~~**Lunar Time rate aligned on TT rate (so on UTC rate)**~~
~~TL – TT has only periodic terms, no secular drift~~

Would lead to a too important new scaling of masses and distances for bodies in the solar system

Moon reference time – Current situation

Extensive theoretical analysis and evaluation of 3 options for the definition of a Lunar reference time scale.

Scientific consensus to prefer a Lunar Time defined at the center of the Moon but some space agencies prefer to have a Lunar Time defined close to the Moon surface for operational reasons.

→ Not ready yet for a consolidated CGPM draft resolution with a final choice of the preferred Lunar reference time scale, but we have a draft with some TBC - to be confirmed.

→ Further steps to converge:

- **ICG Annual meeting (19-24 Oct 2025 in Korea)**
- **Workshop on Nov. 18 organized by the CCTF task group with space agencies and future scientific users of Time on the Moon**
- **2nd workshop of the IOAG-ICG in Vienna in Feb. 2026 (with a session on Lunar time)**

Proposed draft CGPM Resolution on the Lunar reference time

The CGPM, at its 28th meeting,

→ **Recommends that**

- for high accuracy operations, providers of Cislunar PNT make use of the international Lunar reference time scale called TL, which is

  Proposed reference time to be confirmed in February 2026

- when a realization of TL is measured with respect to UTC to obtain traceability, the model used to determine the relativistic effects, the input ephemerides, and the associated uncertainties, should clearly be described in addition to the usual procedure to declare traceability

→ **Further recommends** that the BIPM and the NMIs work in collaboration with space agencies and international organizations to support the correct realization of reference time scales, and their measurement with respect to UTC, with the involvement of the UTC community

CCTF

Thank you for your attention

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