CCTF

Roadmap towards the redefinition of the SI second

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Patrizia Tavella BIPM, CCTF Executive secretary
Gianna Panfilo BIPM

on behalf of
CCTF Strategic WG extended to co-chairs of dedicated CCTF WGs
CCTF Task Force on the Roadmap towards the redefinition of the second

Bureau International des Poids et Mesures

CCTF HOT TOPICS

The **Consultative Committee on Time and Frequency** is concentrating on 4 hot topics:

→ **Updating the roadmap towards the redefinition of the SI second** **40 persons contributing**

Roadmap and mandatory criteria (N. Dimarcq CIPM, P. Tavella BIPM)

A. Request from user communities, NMIs and Liaisons (M. Gertsvolf, NRC; G. Mileti, Uni Neuchatel)

B. Atomic frequency standards, and possible redefinition approaches (S. Bize, SYRTE; E. Peik, PTB; C. Oates, NIST)

C. TF Dissemination and time scales (D Calonico, INRIM; T. Ido NICT)

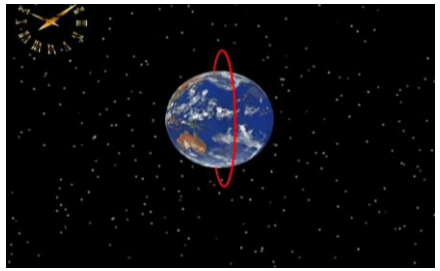
→ **Leap seconds in UTC and building a consensus for a continuous timescale**
(J. Levine, NIST; P. Tavella, BIPM)

→ **Promoting the mutual benefit of UTC and GNSS, subgroup on Traceability to UTC from GNSS measurement**
(P. Defraigne, ORB; A. Bauch, PTB)

→ **Sharing Resources to Improve the International Timekeeping by Capacity Building**
(M. Gertsvolf NRC, Y. Hanado, NICT)

Definitions of the SI unit of time

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



Astronomy (angle/phase of a linear process)

→ **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 (frequency of a periodic process)

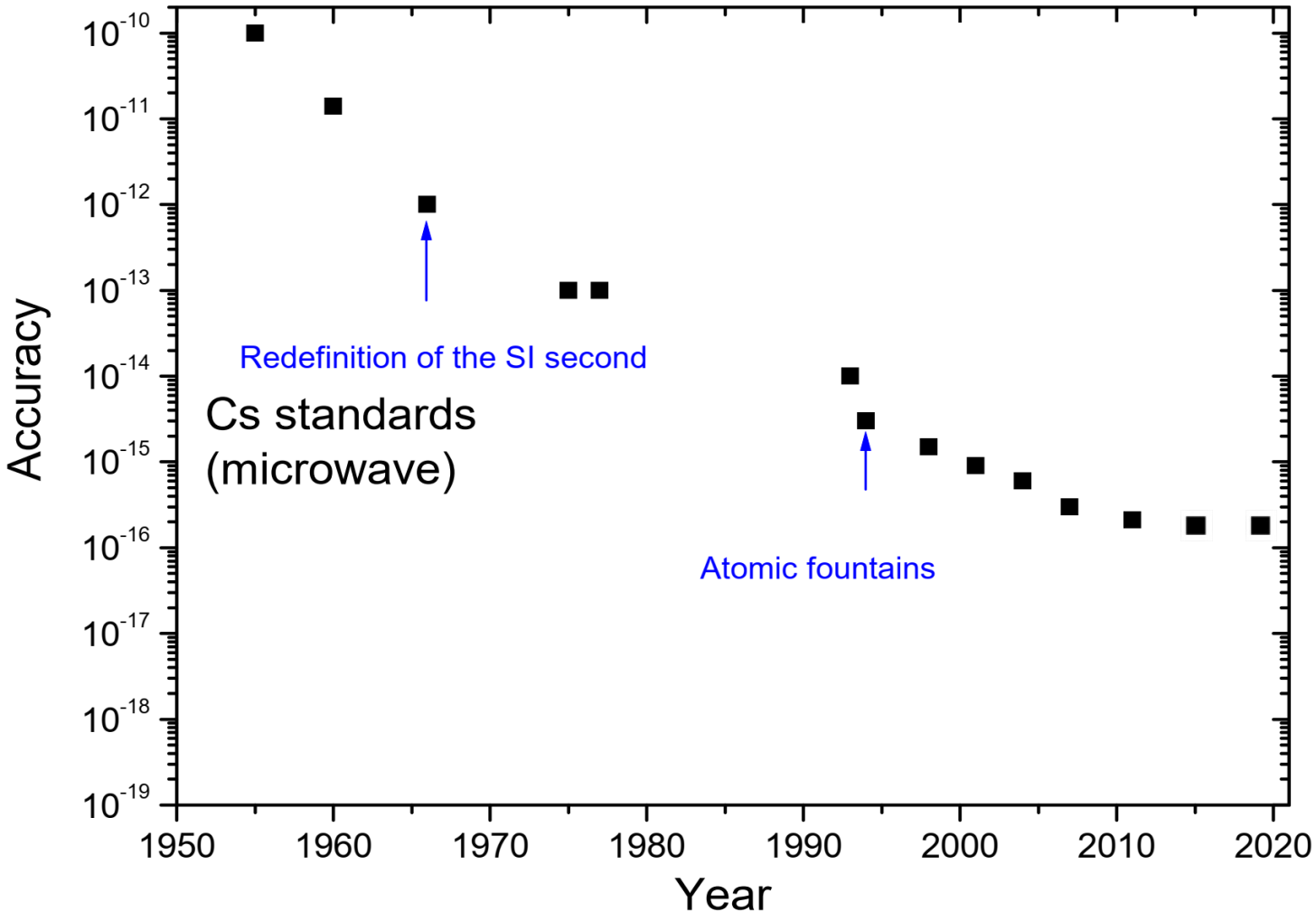
→ **1967 : the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom**

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}.

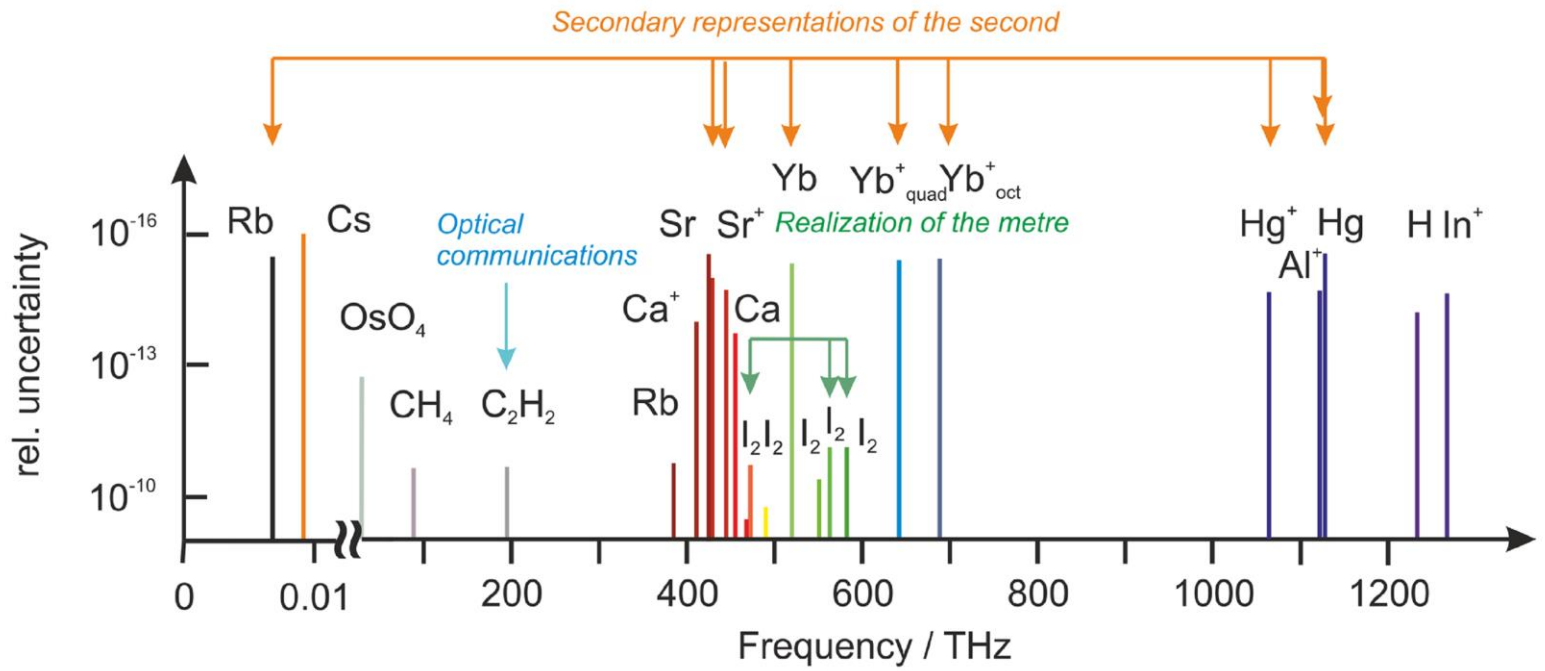
Realization of the SI second with primary Cs frequency standards



Cs fountain accuracy
$\sim 10^{-16}$

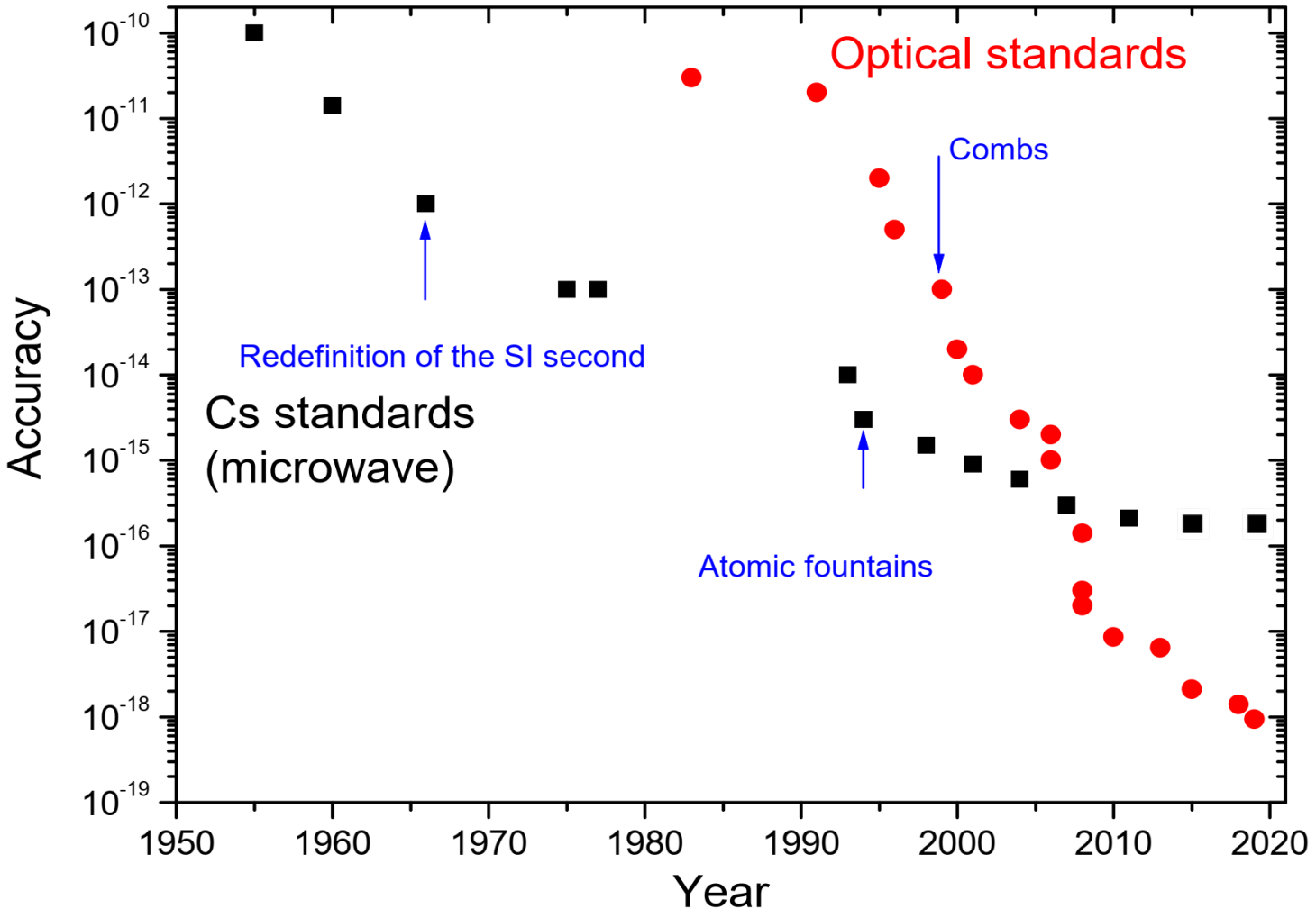
Secondary representations of the second

List of recommended standard frequencies (validated by CIPM, published on the BIPM website) recommended for applications including the practical realization of the metre and secondary representations of the second



	2020 rec value	2020 rec unc
115In+	1267402452901041.3	4.3E-15
1H	1233030706593514	9.0E-15
199Hg	1128575290808154.32	2.4E-16
27Al+	1121015393207859.16	1.9E-16
199Hg+	1064721609899146.96	2.2E-16
171Yb+(E2)	688358979309308.24	2.0E-16
171Yb+(E3)	642121496772645.12	1.9E-16
171Yb	518295836590863.63	1.9E-16
40Ca	455986240494140	1.8E-14
88Sr+	444779044095486.3	1.3E-15
88Sr	429228066418007.01	2.0E-16
87Sr	429228004229872.99	1.9E-16
40Ca+	411042129776400.4	1.8E-15
87Rb	6834682610.9043126	3.4E-16

The era of Optical Frequency metrology



Optical Frequency Standards (Sr, Yb, Yb+, Al+, Ca+, …) at 10^{-18} level

→ Time to change the definition?

Goals for a new definition

→ **Offer an improvement** by 10 to 100 of the realization of the new definition on short term after the redefinition (reaching 10^{-17} to 10^{-18} relative frequency accuracy) and a larger improvement on longer term

→ **Ensure continuity with the current definition**

→ **Ensure continuity and sustainability of the availability of the new SI second** through TAI, and a **significant improvement of the quality of TAI** as soon as the definition is changed (at least no degradation !)

→ **Enable the dissemination of the unit** towards wide categories of users

→ **Be acceptable** by all NMIs and stakeholders

Priority setting of criteria / conditions to change definition

Frequency standards & contribution to atomic time scales

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**
- 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 (III.4)
- Improved quality of the dissemination towards users (III.5)

Priority setting of criteria / conditions to change definition

TF comparison and dissemination

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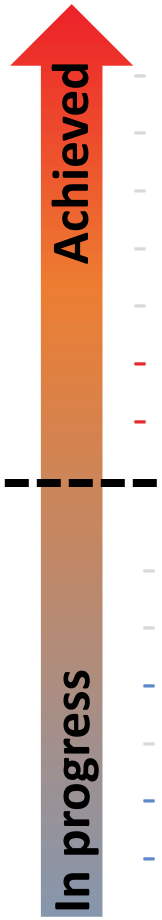
Priority setting of criteria / conditions to change definition

Acceptability of the new definition



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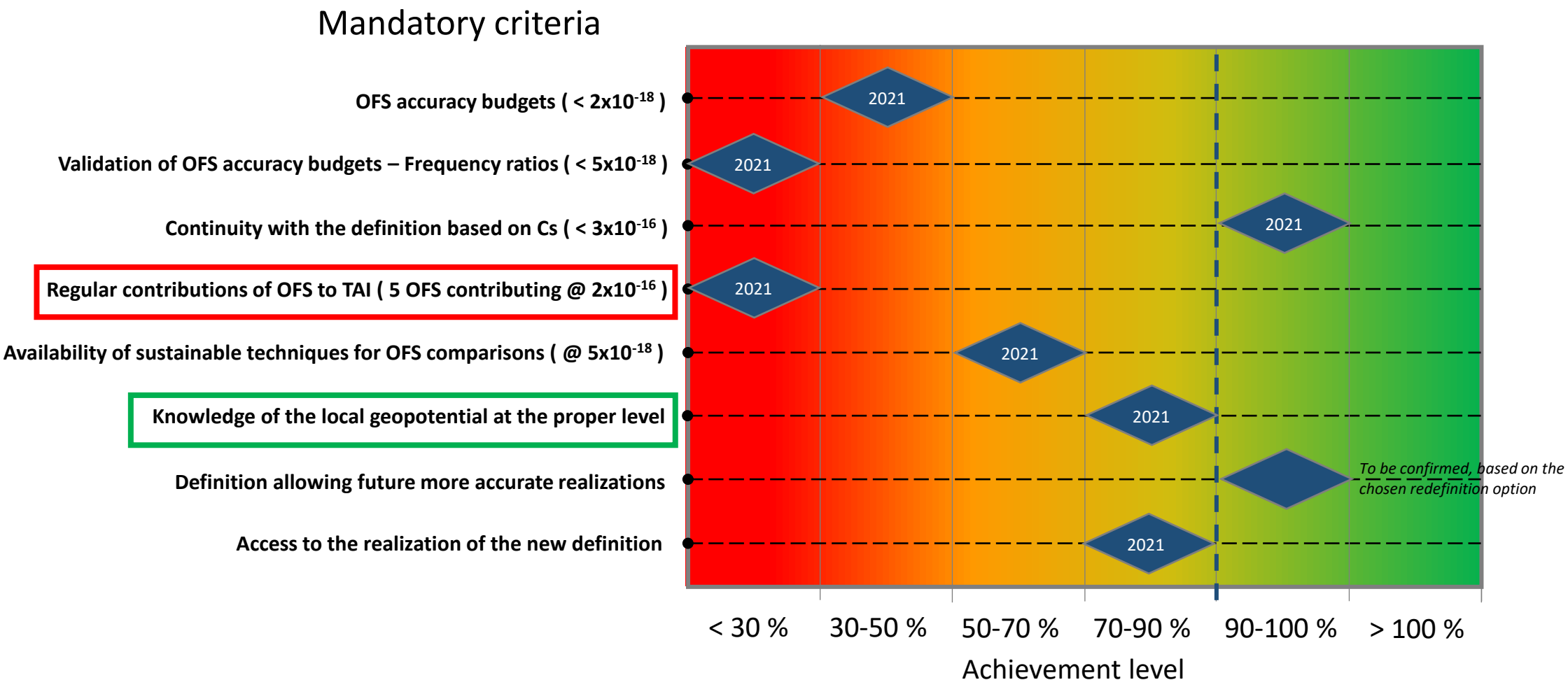
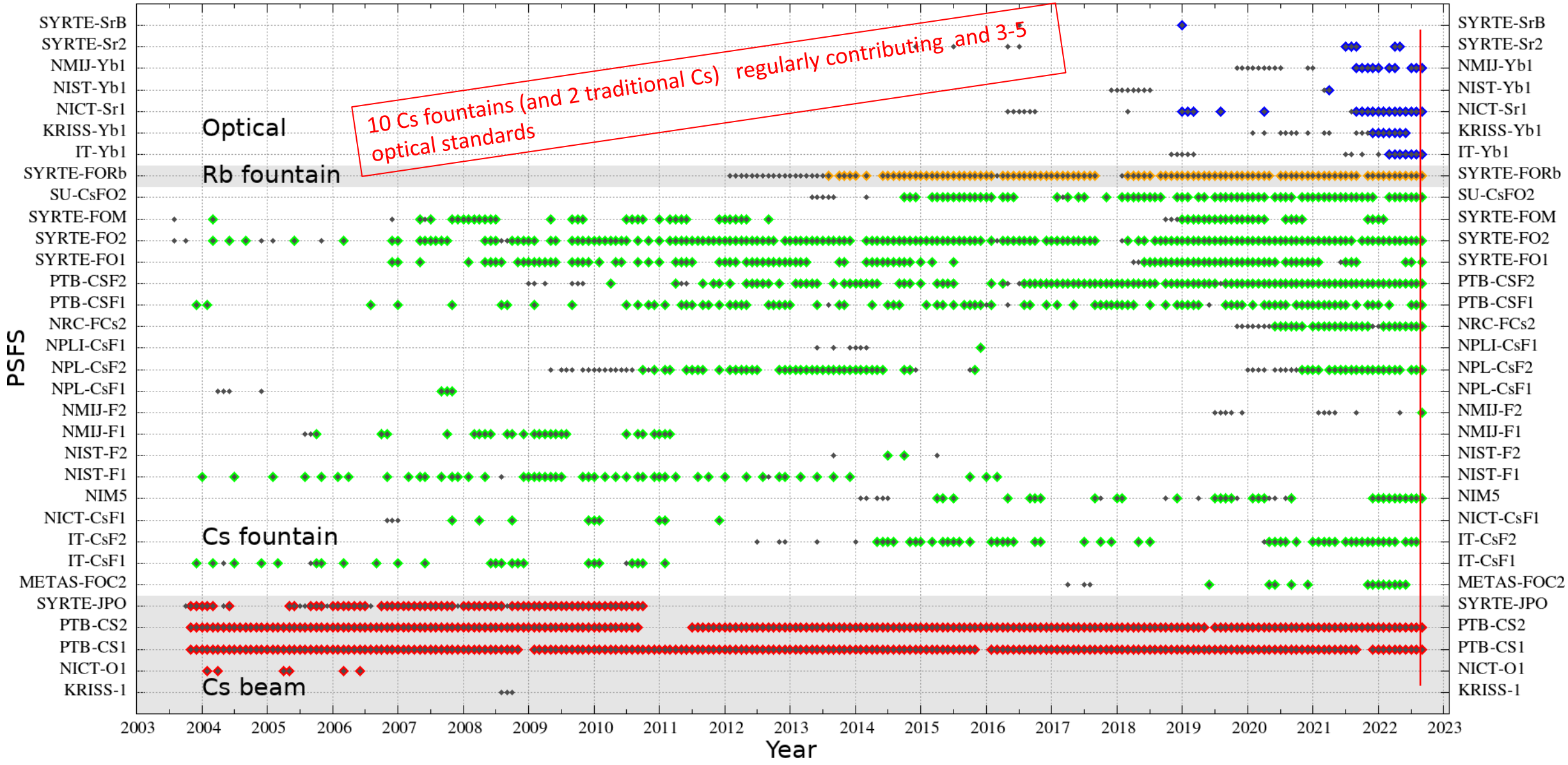
Fulfilment level of mandatory criteria



Contribution from Primary and Secondary Frequency Standards to TAI



Monthly updated plot https://webtai.bipm.org/database/show_psfs.html

Options for the redefinition of the second

Option 1: Single atomic transition
Definition: fix the frequency of a single (optical) atomic transition

$$\Delta\nu_{\mathrm{Cs}} = 9\ 192\ 631\ 770\ \mathrm{Hz}$$

Option 2: Ensemble of transitions on an even basis
Definition: weighted geometric mean of an ensemble C of chosen transitions
Weight inversely proportional to the uncertainty of best standard using transition i

See J. Lodewyck, Metrologia 56, 055009 (2019)

$$\nu = \frac{1}{N}\prod_{i\in\mathcal{C}} \nu_i^{w_i}$$

Option 3: Fixing the value of another fundamental constant
Definition: fix the value of one more fundamental constant

$$X, c, h, e, k$$

Unfortunately not realist as there is no fundamental constant known with adequante accuracy

Scenarios for the redefinition of the second

CGPM 2022 2026 2030 2034 ….

A redefinition at CGPM 2026 is unrealistic since today there is no consensus on the preferred option and still some important work to do to fulfil all mandatory criteria.

CGPM 2026 could validate a roadmap towards a redefinition in 2030 if, in 2026, there is a consensus on the redefinition option to be chosen and if the work to fulfil mandatory criteria is likely to be achievable by 2030.

If it is not possible in 2030, the redefinition will have to be postponed, at CGPM 2034 or the following one… But what about maintaining until the late 2030s the operation of Cs fountains that have been built in the 1990s - 2000s

The CCTF has proposed

to the 27th General Conference on Weights and Measures (CGPM) 2022

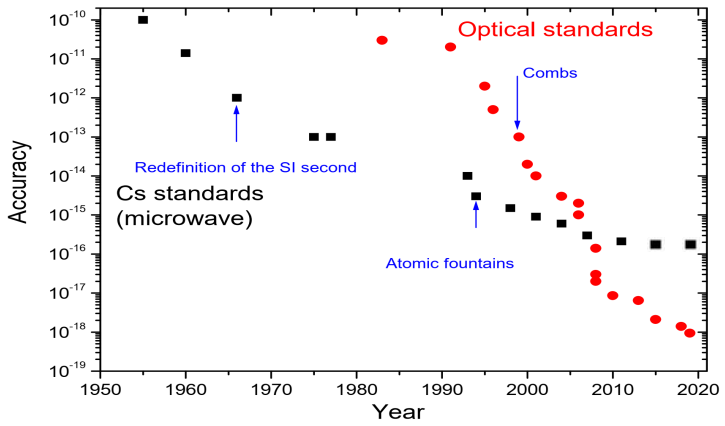
the draft Resolution E – On the future re-definition of the second

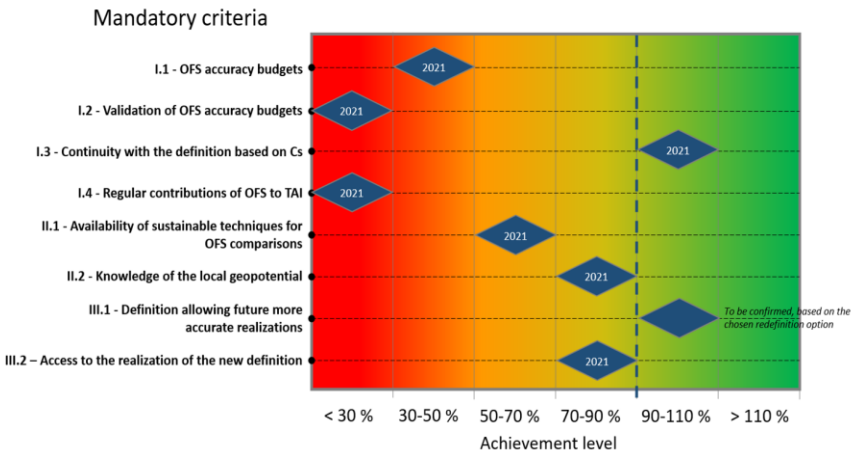
noting *that optical frequency standards in many NMIs have surpassed the accuracy achievable by the realization of the current definition by a factor of up to 100, and that the CCTF has prepared a roadmap of the actions and timings needed to decide on a new definition of the second and has established criteria and appropriate indicators in order to monitor progress towards such a new definition,*

encourages *the CIPM to promote the importance of achieving the targets proposed in the roadmap for the redefinition of the second, such that sufficient progress will have been made for the CGPM to decide at its 28th meeting in 2026 to agree on a new definition for implementation in 2030,*

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.*

Most challenging issue: support the development of optical frequency standards and the time and frequency transfer link to fulfill the mandatory criteria





CCTF

Thanks to CCTF and its WGs, NMIs, experts, BIPM and concerned bodies for all their past, present and future contributions

Thanks for your attention

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