CCTF Task Force on the Redefinition of the Second

SG-3 Education and Communication

Technical Exchange

CONSULTATIVE COMMITTEE
FOR TIME AND FREQUENCY

Apr 28, 2025

Definition of the second

CGPM resolution 9 (1960):

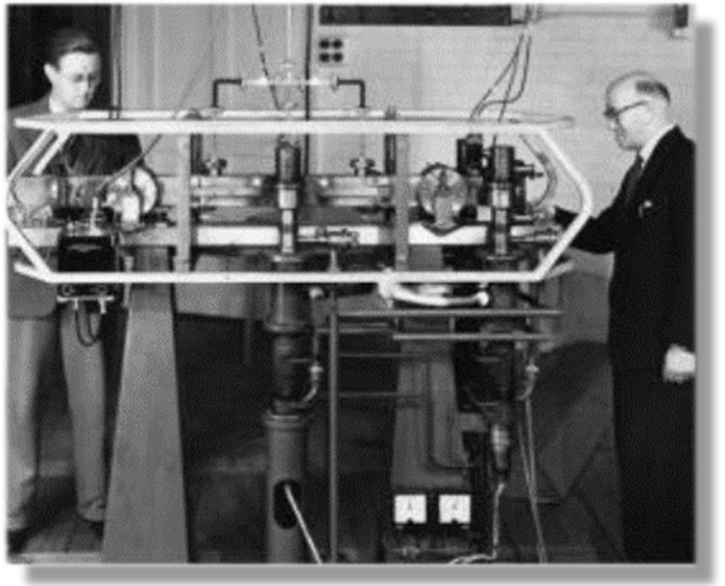
The second is the fraction 1/31 556 925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time.

CGPM resolution 1 (1967):

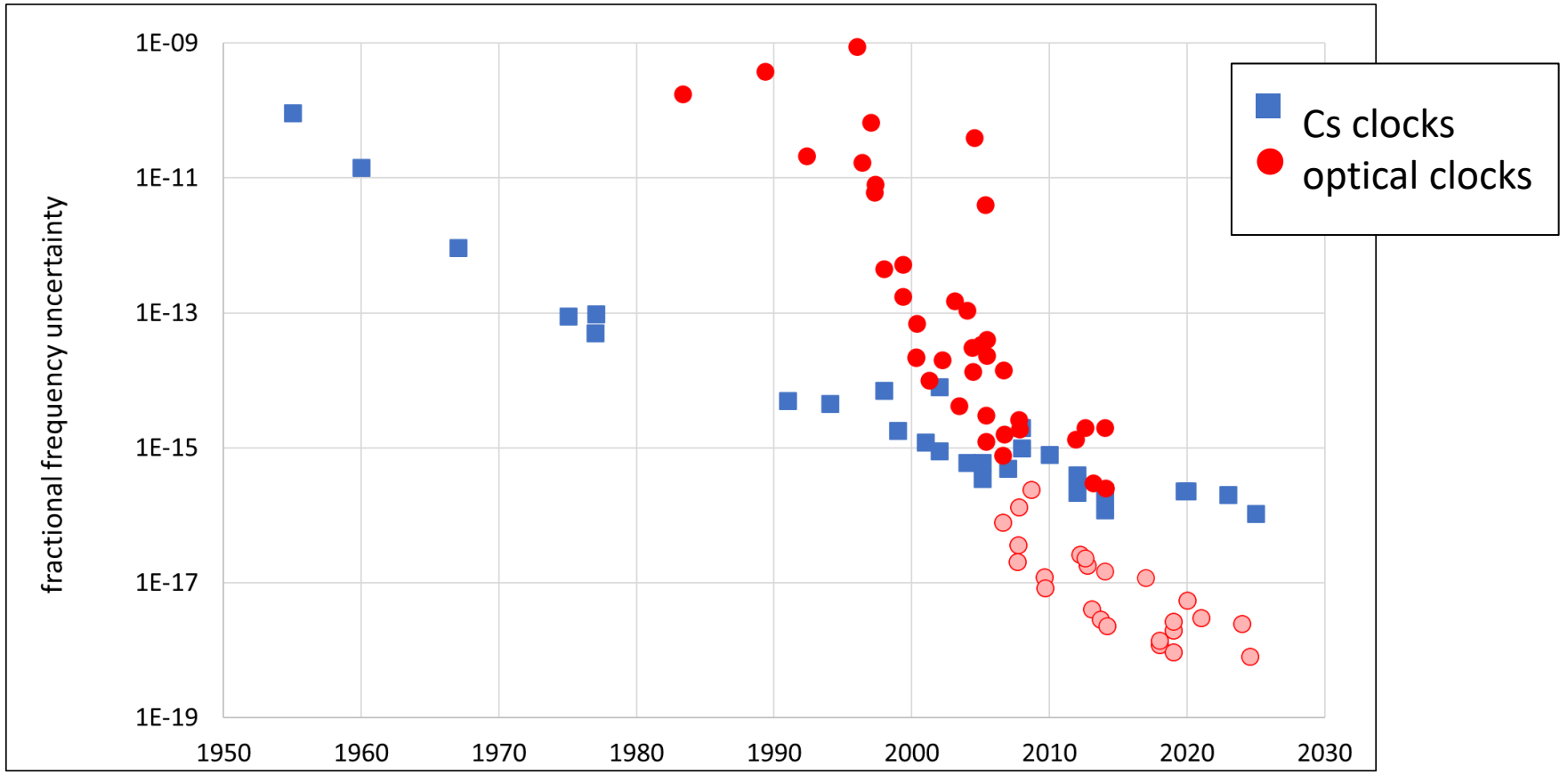
The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom

CGPM resolution 1 (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}.



Essen & Parry (NPL, 1955)



1 / 86 400 of the mean solar day

1960

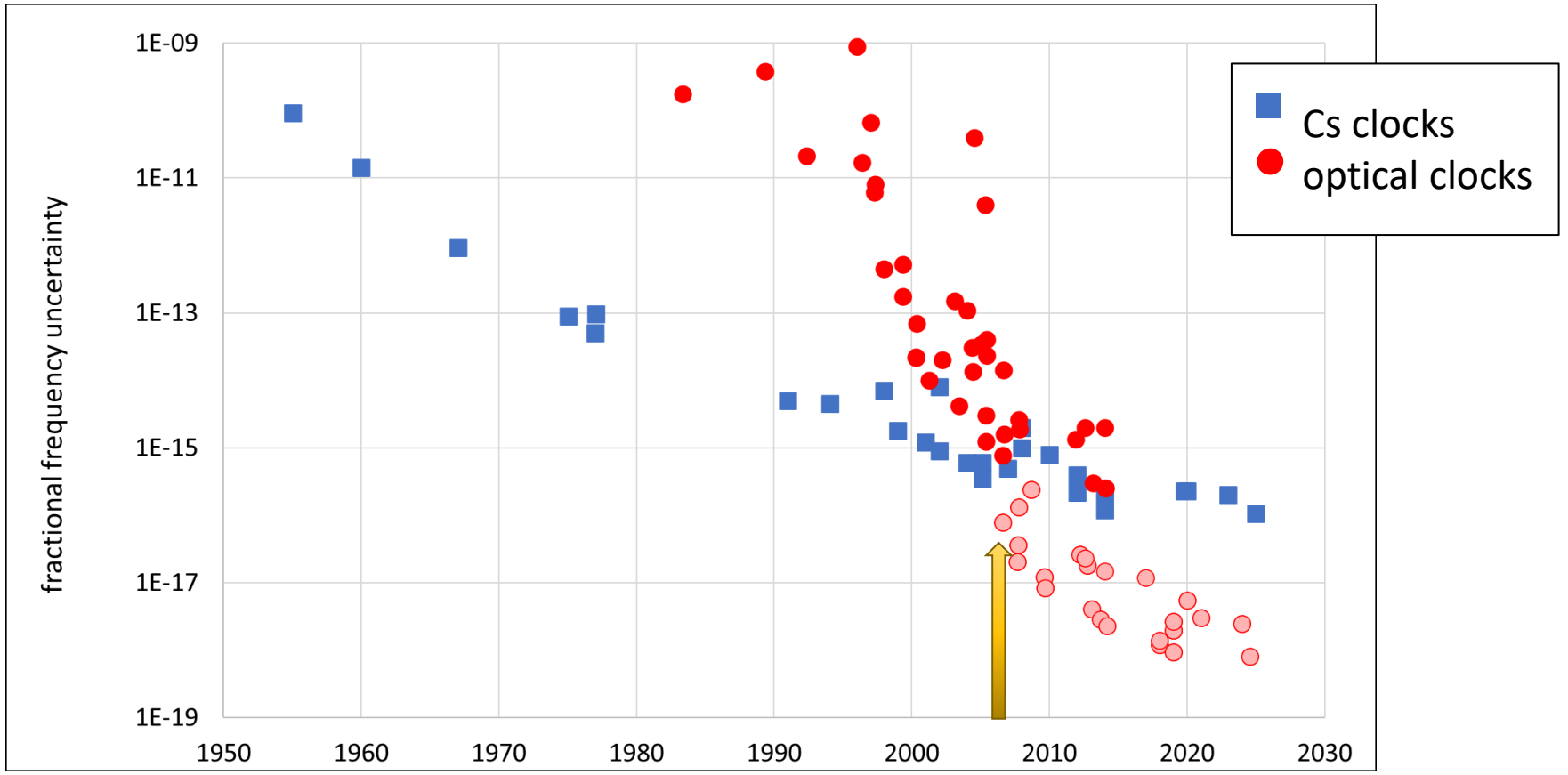
1/31 556 925.9747 of the tropical year 1900 January 0 at 12 hours ephemeris time

1967

9 192 631 770 periods of ^{133}Cs ground state hyper-fine transition

2018

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



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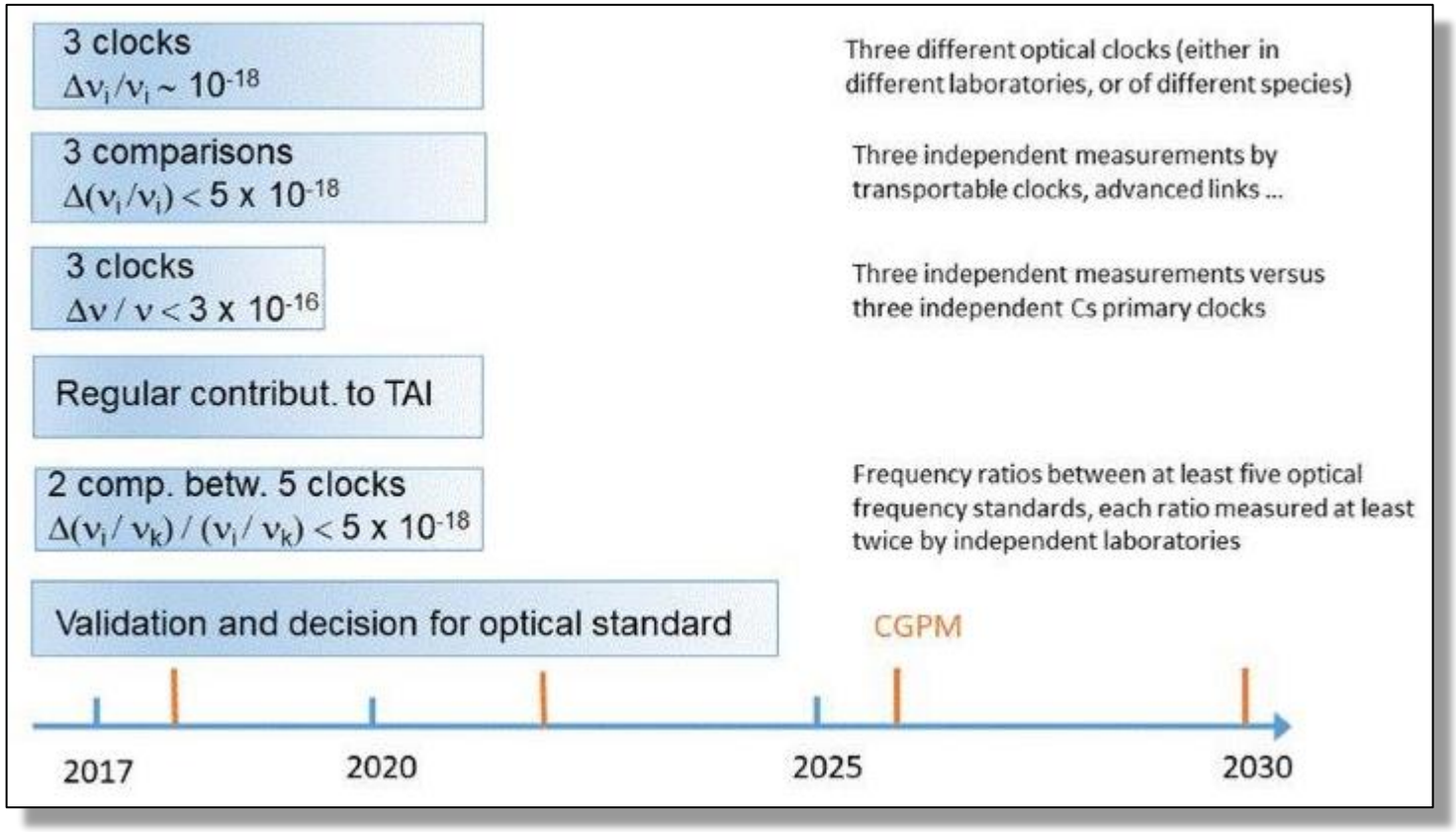
CCTF **Roadmap** towards a redefinition of the second



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CCTF Roadmap towards a redefinition of the second

2020

CCTF **Updated** roadmap towards a redefinition of the second

1) Conditions to change definition: Frequency standards and TAI

Validation that optical standards and optical frequency metrology are at level 100 better than Cs

I.1) At least 3 different optical clocks (of the same type in different laboratories and of different types in either the same laboratory or different laboratories) have demonstrated validated uncertainties $< 2 \times 10^{-18}$, with comprehensive and published accuracy budgets

I.2) Optical frequency ratios between a few (at least 5) other optical frequency standards have been performed, each ratio measured at least twice in independent laboratories and repeated over an extended period with an agreement $\Delta\nu/\nu < 5 \times 10^{-18}$

Continuity with the definition based on Cs

I.3) There are at least 3 independent measurements of the optical frequency standards listed in (I.1) with TAI or with three independent Cs primary clocks (in different or same labs), where the measurements are limited essentially by TAI or by the uncertainty of these Cs fountain clocks (e.g. $\Delta\nu/\nu < 3 \times 10^{-16}$)

Availability through TAI/UTC by regular contributions of optical clocks to TAI (as secondary representations of the second)

I.4) More than 3 state-of-the-art contributions (uncertainty $< 2 \times 10^{-16}$) to TAI each month from a set of at least 5 independent optical standards for at least 1 year. Test of degradation of TAI with new PFS (+ Cs fountains as SFS)

must be achieved

Reliability of optical standards

I.5) Optical clocks TRL > 4 (to be confirmed) and reliable continuous operation capability over durations > 10 days (to be confirmed)

Regular contributions of optical clocks to UTC(k)

I.6) Optical clocks calibrating TAI contribute also to the steering of UTC(k) produced by the concerned NMIs

can be still in progress

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2) Conditions to change definition: TF comparison and dissemination

Capability to compare optical frequency standards operating in different institutes

II.1) Availability and sustainability of T/F links with uncertainties $< 5 \times 10^{-18}$ in frequency between NMIs operating optical frequency standards, on a national / continental scale

II.2) At least 3 independent measurements of all optical clocks in (I.1) compared between different institutes (e.g. $\Delta\nu/\nu < 5 \times 10^{-18}$) either by transportable clocks, advanced links, or frequency ratio closures

II.3) For NMIs operating optical frequency standards with accuracy $< 5 \times 10^{-18}$:
- to fulfil II.1) and II.2), knowledge of geopotential differences with uncertainties $< 5 \times 10^{-18}$
- for TAI calibration, knowledge of geopotential with uncertainties $< 1 \times 10^{-17}$

must be achieved

Effectiveness and sustainability of dissemination

II.4) Capability of repeated uncertainty estimations and calibrations for T/F links

II.5) T/F links TRL > 6 (to be confirmed) and reliable continuous operation capability over durations > 30 days (to be confirmed)

Wide dissemination of the realization of the definition

II.6) Availability of T/F links with uncertainties $< 5 \times 10^{-18}$ in frequency at national / continental / worldwide scale for TF comparisons and dissemination

II.7) Knowledge of geopotential with uncertainties:
- $< 2 \times 10^{-18}$ for NMIs operating optical frequency standards with accuracy $< 5 \times 10^{-18}$
- $< 2 \times 10^{-17}$ for a larger number of NMIs and high accuracy user categories

can be still in progress

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3) Acceptance criteria of the new definition

Continuity with present definition and long lasting capacity of the new definition

- III.1) Potential for ultimate level of accuracy achievable on frequency standards, in time realization, in TAI. Definition allowing future more accurate realizations
- III.2) Cs frequency standards ensure a secondary realization of the new definition
- III.3) Commitment of NMIs to:
  - Operate optical clocks providing primary or secondary realization of the new definition (reliable operation, regular contribution to TAI, …)
  - Maintain and operate Cs fountain standards

Broad access to the new definition

- III.4) Facility of access to the realization of the new definition by a large number of NMIs and high accuracy user categories
- III.5) Acceptability of the new definition by NMIs who do not have optical clocks to realize the new definition. Autonomy of each country

must be achieved

Public access to the new definition

- III.6) Realization / “mise en pratique” easily understandable with clear uncertainty evaluation process
- III.7) Availability of commercial optical clocks
- III.8) Capacity of dissemination to low accuracy users

can be still in progress

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CCTF Updated roadmap towards a redefinition of the second

2022

CGPM **Resolution 5**: On the future redefinition of the second

CGPM resolution 5 (2022):

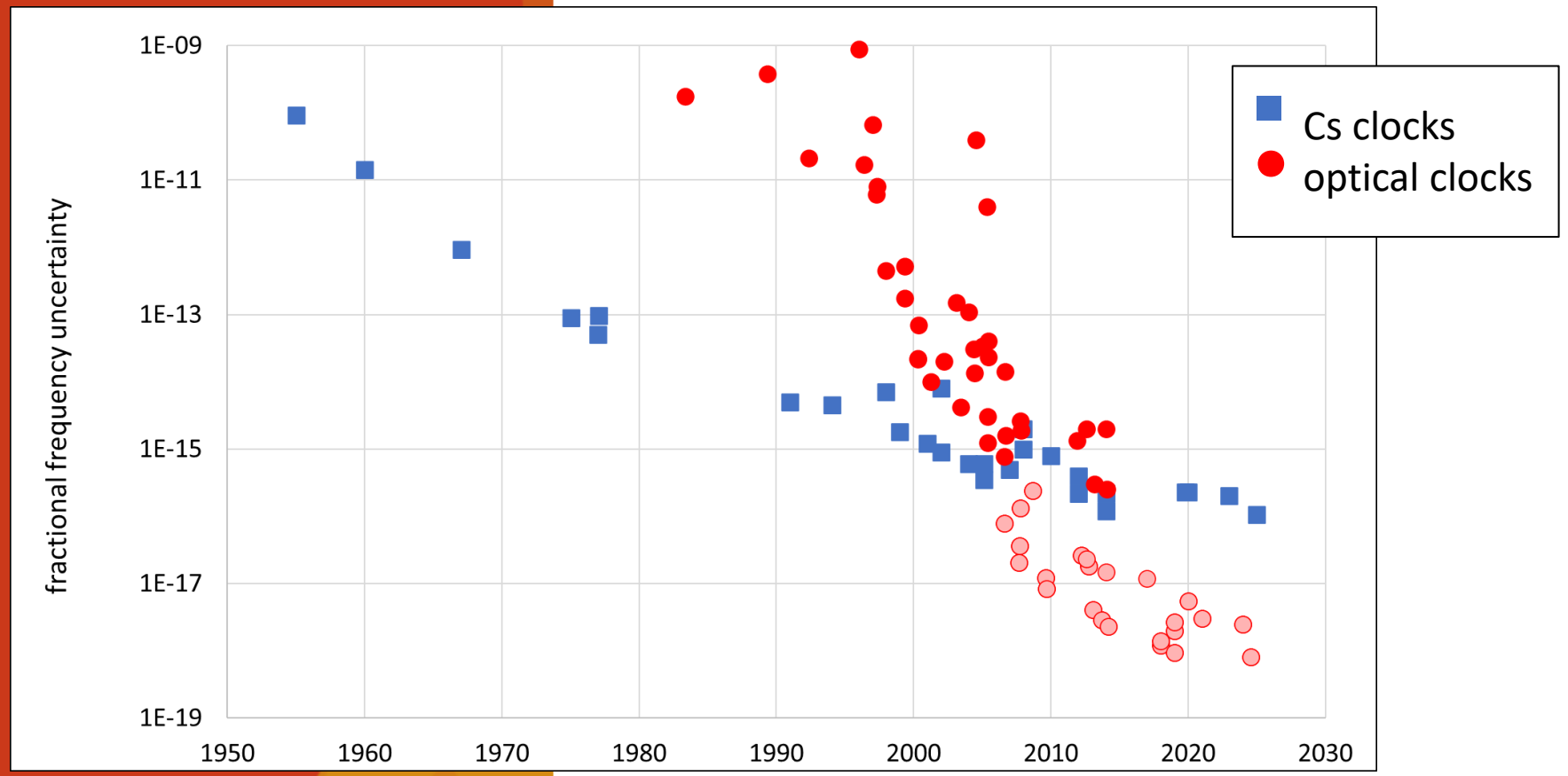
encourages the International Committee for Weights and Measures (CIPM)

- 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.

CGPM

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



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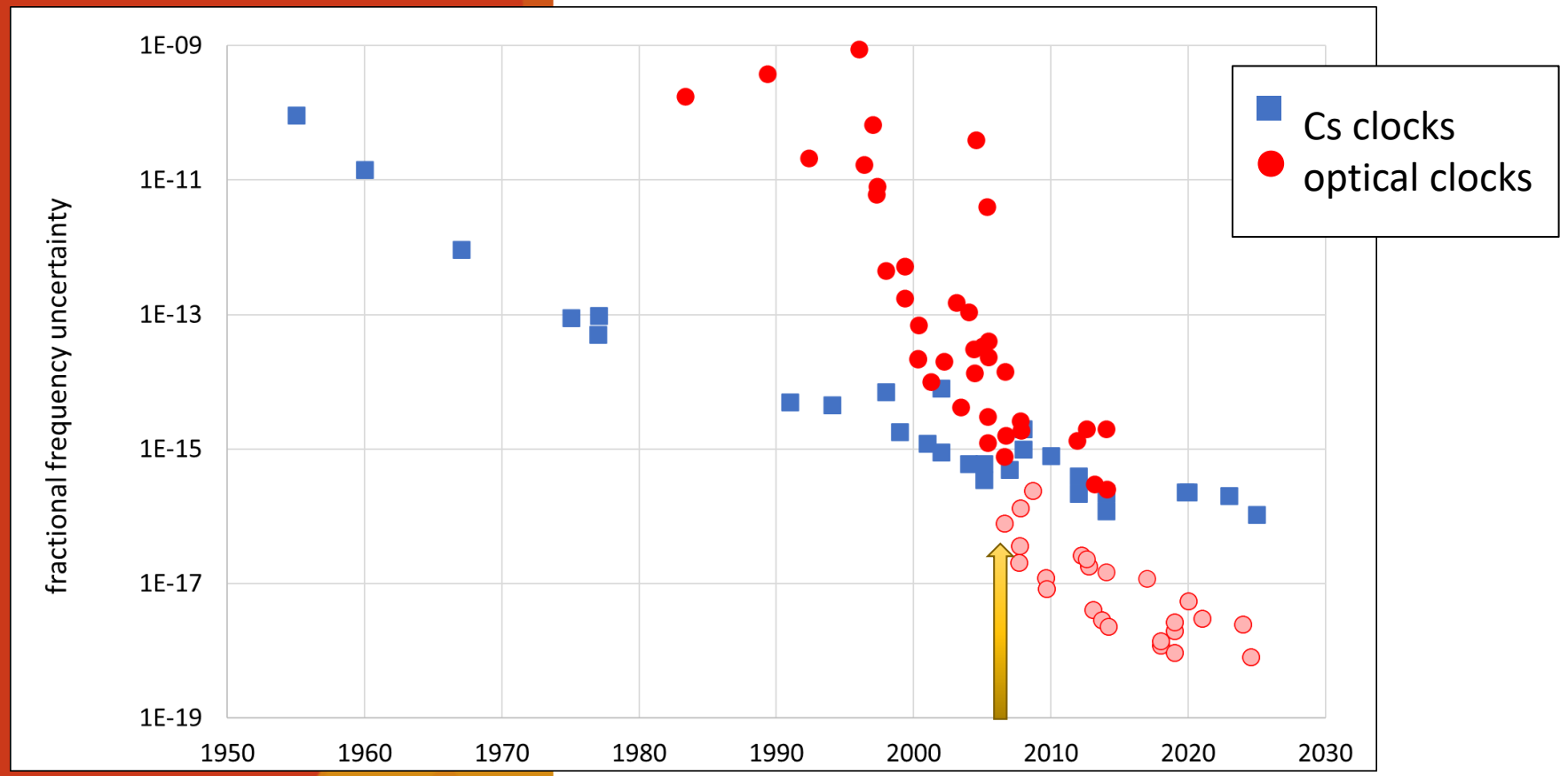

New definition is needed

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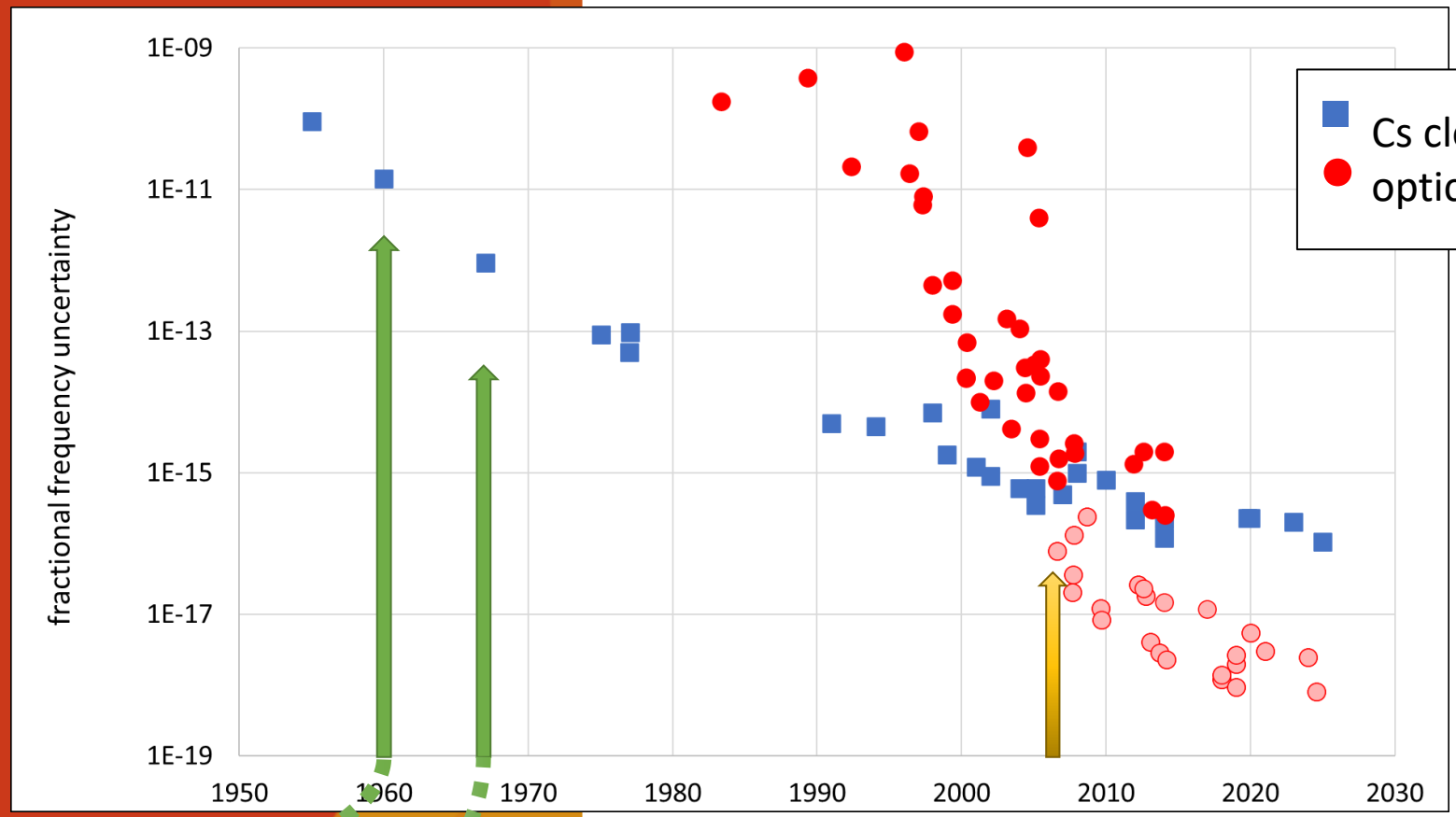

Redefinitions in the 70s

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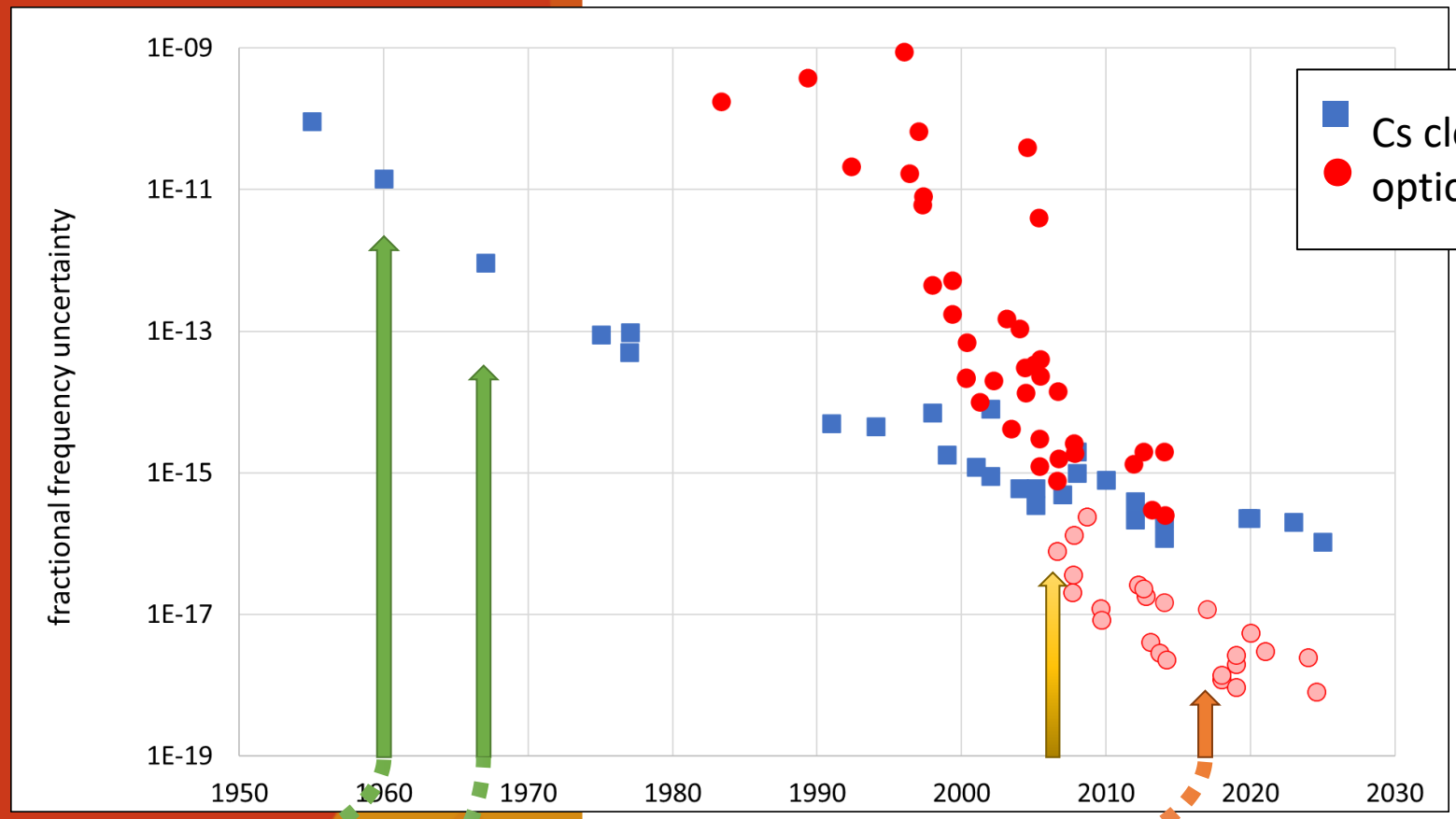

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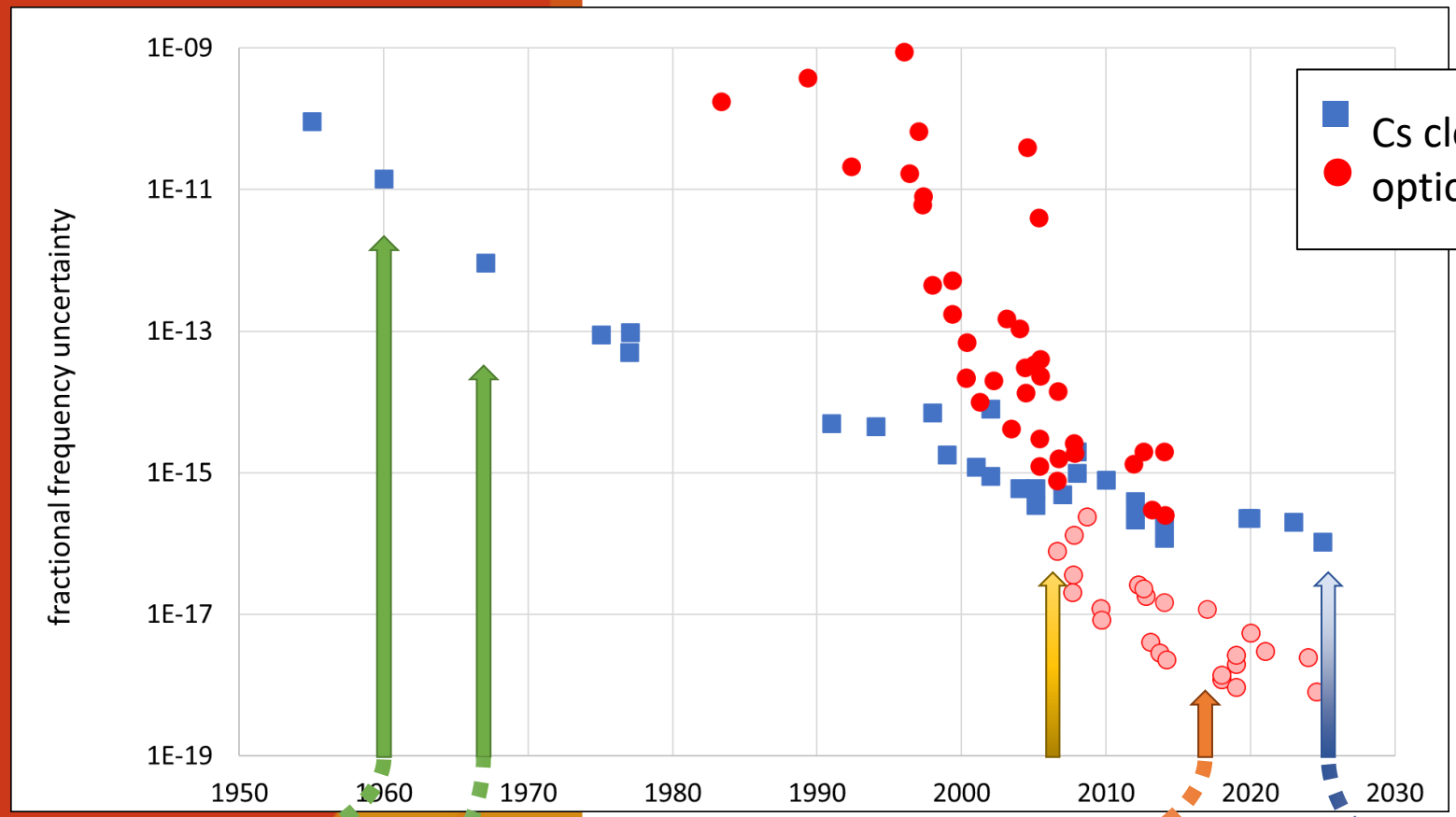

Redefinition option selected

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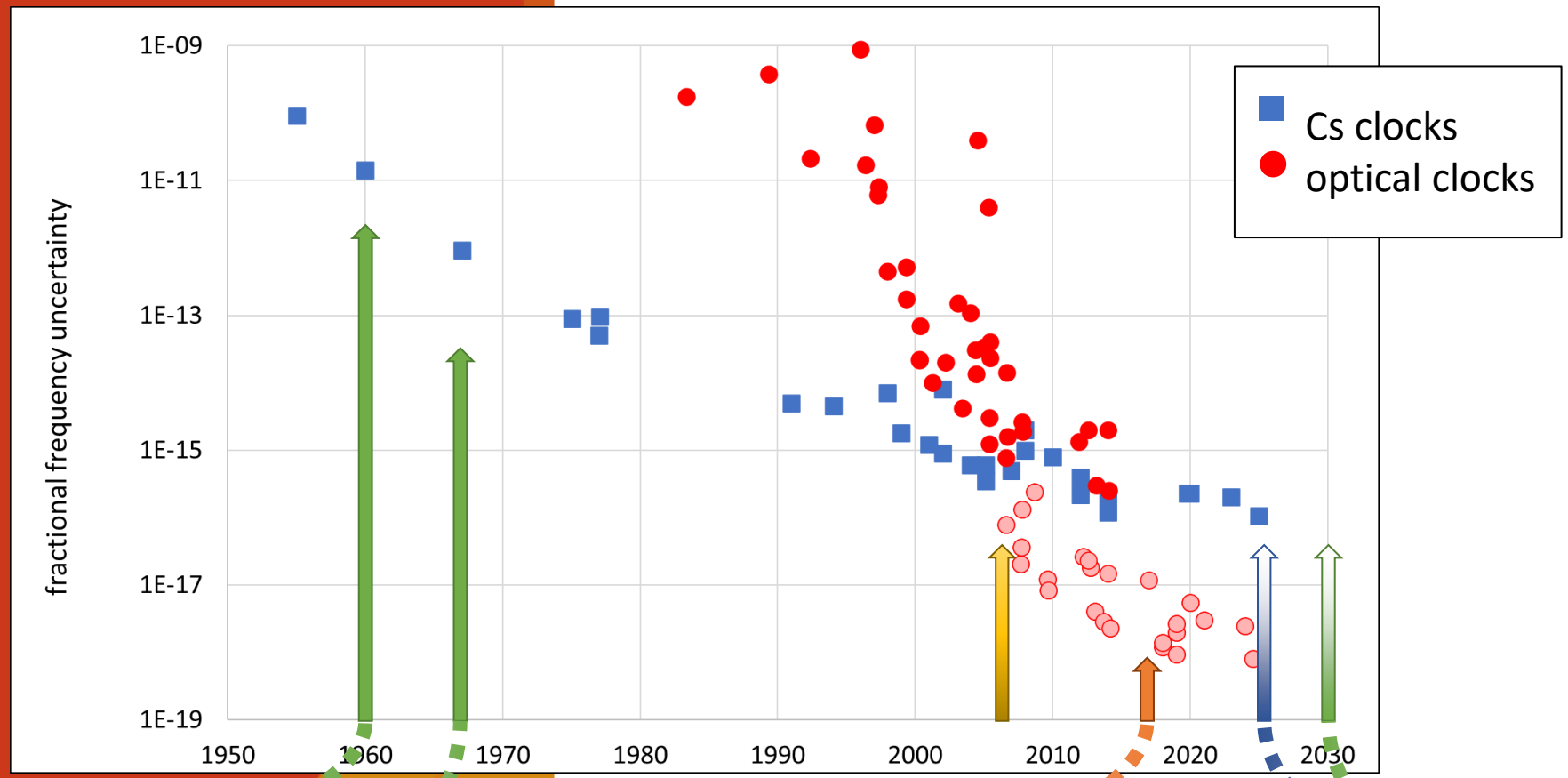
2017 CCTF Roadmap towards a redefinition of the second

2020 CCTF Updated roadmap towards a redefinition of the second

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



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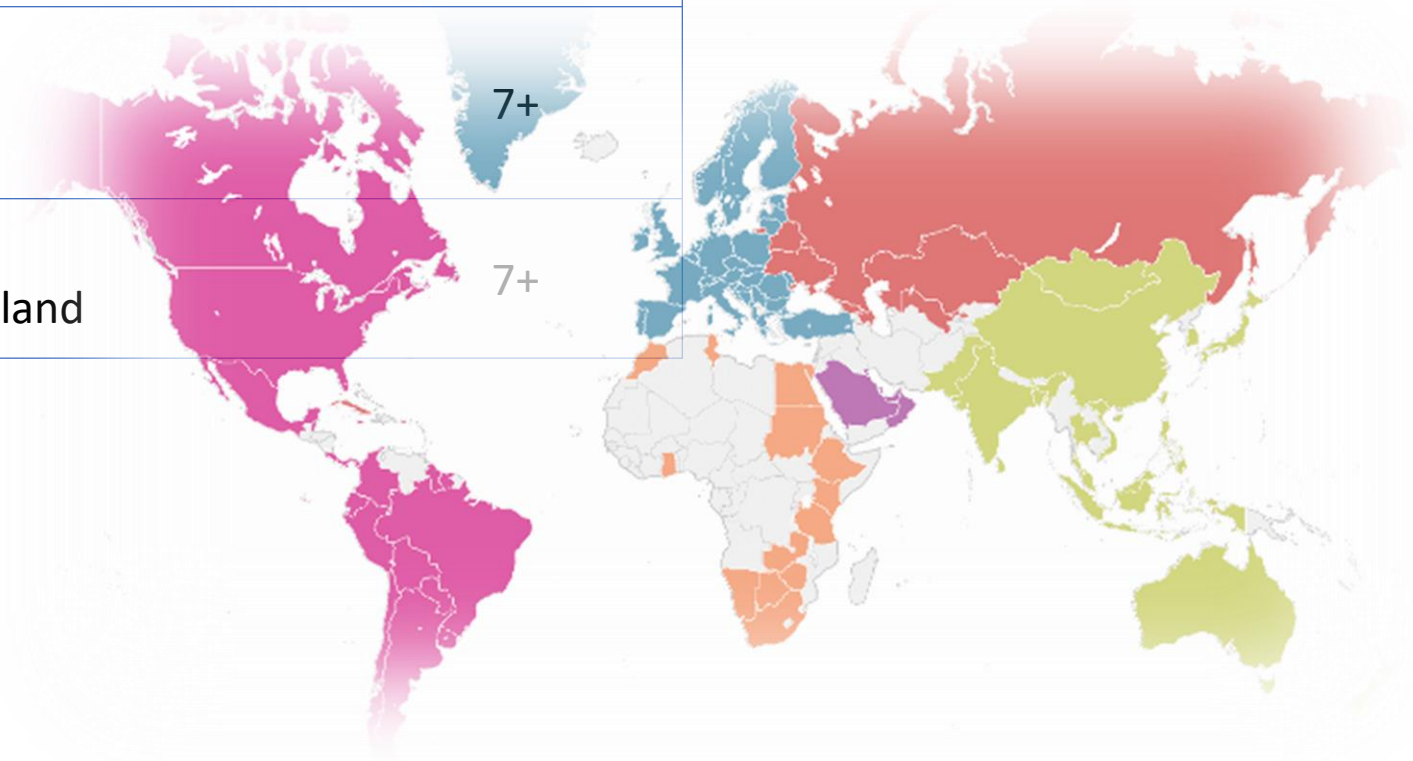
CCTF Task Force on the Redefinition

Sub-Group Name	Sub-Group Co-Chairs	# members
1-Options	S. Bize, SYRTE, France E. Peik, PTB, Germany F. Fang, NIM, China	14+
2-Criteria	D. Calonico, INRIM, Italy T. Ido, NICT, Japan S. Weyers, PTB, Germany	7+
3-Education	M. Gertsvolf, NRC, Canada G. Mileti, UNeuchâtel, Switzerland	7+



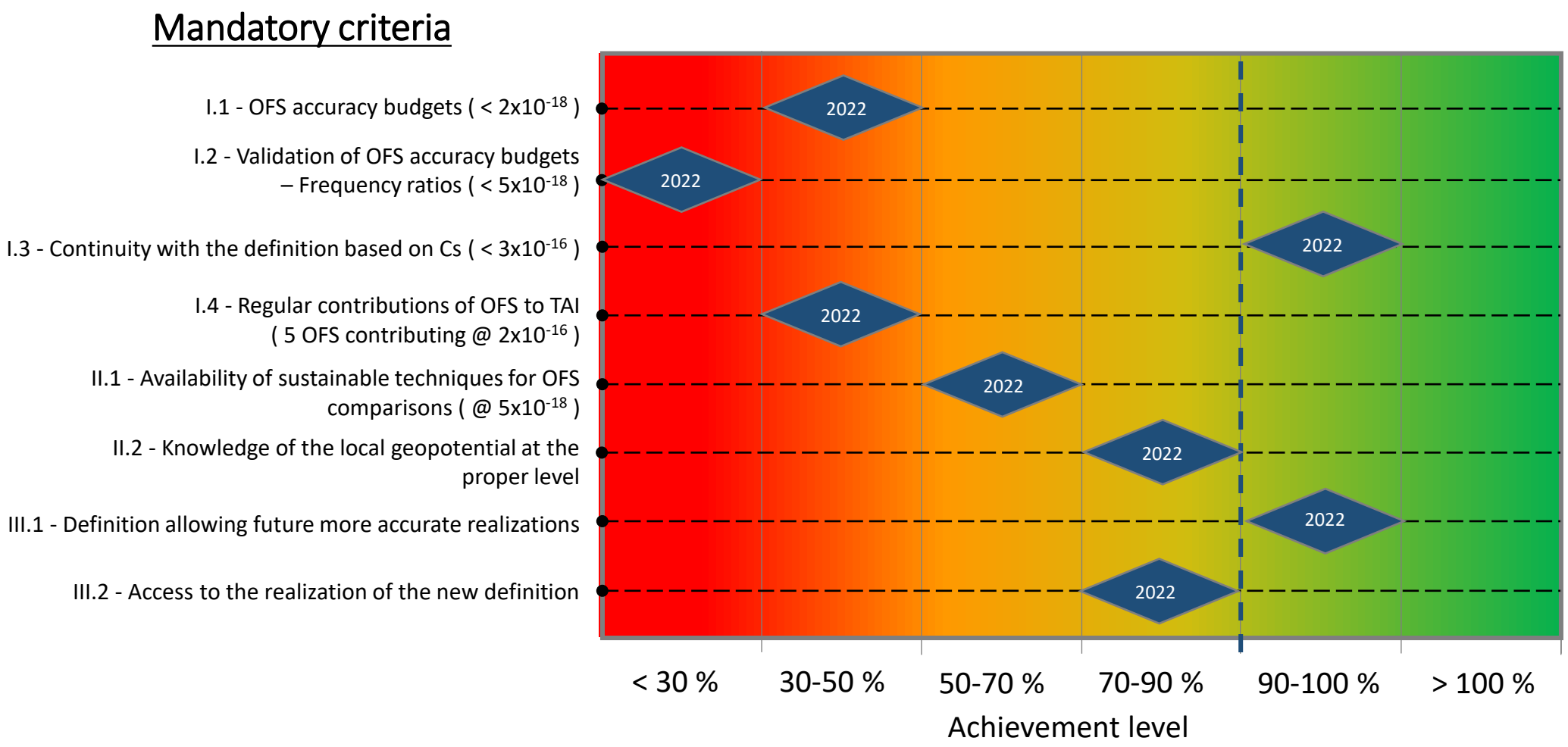
CCTF Task Force on the Redefinition

Sub-Group Name	Tasks
1-Options	➢ Define different options for the redefinition ➢ Provide analysis on options and species ➢ Make proposals toward a consensus on the choice options/species
2-Criteria	➢ Monitor redefinition criteria fulfilment levels progress ➢ Identify criticalities and propose mitigating actions
3-Education	➢ Develop communication information and tools related to the redefinition for CCTF, NMI, UTC(k) and general public

Redefinition Options (SG-1)

Option 1	Option 2	Option 3
one single atomic transition in lieu of the Cs	weighted geometrical mean of the frequency of an ensemble of chosen transitions. **2a**: fixed (CGPM) list of ν_i, w_i, N **2b**: live (CIPM) list of ν_i, w_i, N, according to rules (CGPM)	fixing the numerical value of one more fundamental constant
$\nu_{\mathrm{Xy}} = N$ Hz, where N is the defining value	$\prod_i {\nu_i}^{w_i} = N$ Hz, where w_i and N are the defining values	$m_e = M$ kg, where M is the defining value, completed by the other defining relations for c, h, e, k_B, N_A and K_{cd}
Example: $\nu_{^{87}Sr} = 429\,228\,004\,229\,872.99$ Hz	Example: $\left(\nu_{^{87}Sr}\right)^{0.25}\left(\nu_{^{171}Yb}\right)^{0.25}\left(\nu_{^{171}Yb^+(E3)}\right)^{0.2}\left(\nu_{^{27}Al^+}\right)^{0.3} = 650464\,137\,090\,812.53$ Hz	

Following the progress of the criteria fulfilment levels (SG-2)



CCTF Task Force work on the redefinition

Since 2020:

- 26 meetings of the CCTF WG SP & TFR
- 10 meetings of the CCTF TFR
- 30+ meetings of CCTF TFR SGs
- 4 CCTF meetings and information sessions
- Technical Exchanges
- Conference plenary talks

Questions remain:

- Option 1 or Option 2?
  - Option 2a or 2b?
- Which species?
- When?

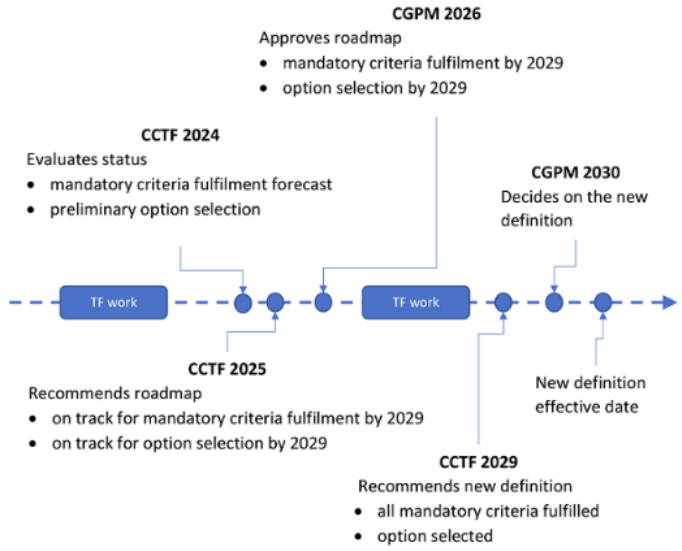
What is the timeline for redefinition?

The timeline for the proposed redefinition of the second is set by meetings of the General Conference on Weights and Measures (CGPM). These are held every four years, with the next meeting scheduled for 2026. Two steps are required at the CGPM:

01 Presentation and consideration of the proposal (earliest date 2026)
02 Ratification of the new definition (earliest date 2030)

Implementation of the new definition would be expected to follow shortly after ratification.

To present the proposal to the CGPM in 2026, the CCTF must have a draft version of the proposal ready for the CCTF meeting in September 2025.



TE schedule

Helen Margolis (NPL, UK)	Least-Squares Analysis for Optimal Determination of Frequency Ratios
Ekkehard Peik (PTB, Germany)	Defining the SI Second via Option 1: Change and Continuity
Jerome Lodewyck (LTE, France) Tetsuya Ido (NICT, Japan)	Defining the SI Second via Option 2: Challenges and Opportunities
Stefan Weyers (PTB, Germany)	Fulfillment for the Redefinition of the SI Second: Criteria and Challenges
Sebastien Bize (LTE, France)	**Moderated discussion between audience and panelists**

Thank you

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CCTF