CCTF

Towards a new definition for the second…

Noël Dimarcq, CIPM member, CCTF President

With contributions from CCTF WG chairs and
Patrizia Tavella, Director of BIPM Time Department

21st NMI Directors and State Representatives meeting
Oct 21th, 2021

Bureau International des Poids et Mesures

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… and a continuous UTC

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CCTF HOT TOPICS

The **Consultative Committee on Time and Frequency** is concentrating on 4 hot topics
for which task groups have been created in 2020 under the CCTF Strategic Planning WG coordination

Dedicated task groups with more than 50 people working together

1. **Task Force on *Updating the Roadmap towards the redefinition of the SI second:***
   - *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)
2. **Leap seconds in UTC and building a consensus for a continuous timescale** (J. Levine, NIST; P. Tavella, BIPM)
3. **Promoting the mutual benefit of UTC and GNSS, subgroup on Traceability to UTC from GNSS measurement** (P. Defraigne, ORB; A. Bauch, PTB)
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CCTF work in progress:

- **CCTF Session 1 in October 2020**: introduction of the topics, main issues, opening of a questionnaire to NMIs, UTC labs, Liaisons, Stakeholders (4 sets of questions)
- From Nov 2020 to Feb 2021, online questionnaire with > 200 answers
- **CCTF session 2 in March 2021** to discuss main expectations/constraints/possible schedule and way forward
- Beginning of July 2021 – Draft CCTF contributions to CPGM and associated documents sent to CCTF members for comments
- September 17, 2021 – Validation of the CCTF contributions to CGPM by the CCTF WG Strategic Planning (takes into account CCTF members feedback)
- **CIPM meeting in October 2021**: CCTF contribution to CGPM in 2022 with 2 draft resolutions
  - *Draft Resolution D – On the use and future development of UTC (+ accompanying document)*
  - *Draft Resolution E – On the future re-definition of the second (+ accompanying document + Roadmap towards the redefinition of the SI second)*

- Beginning of 2022: white paper on each hot topic
- Summer 2022: paper submitted to Metrologia

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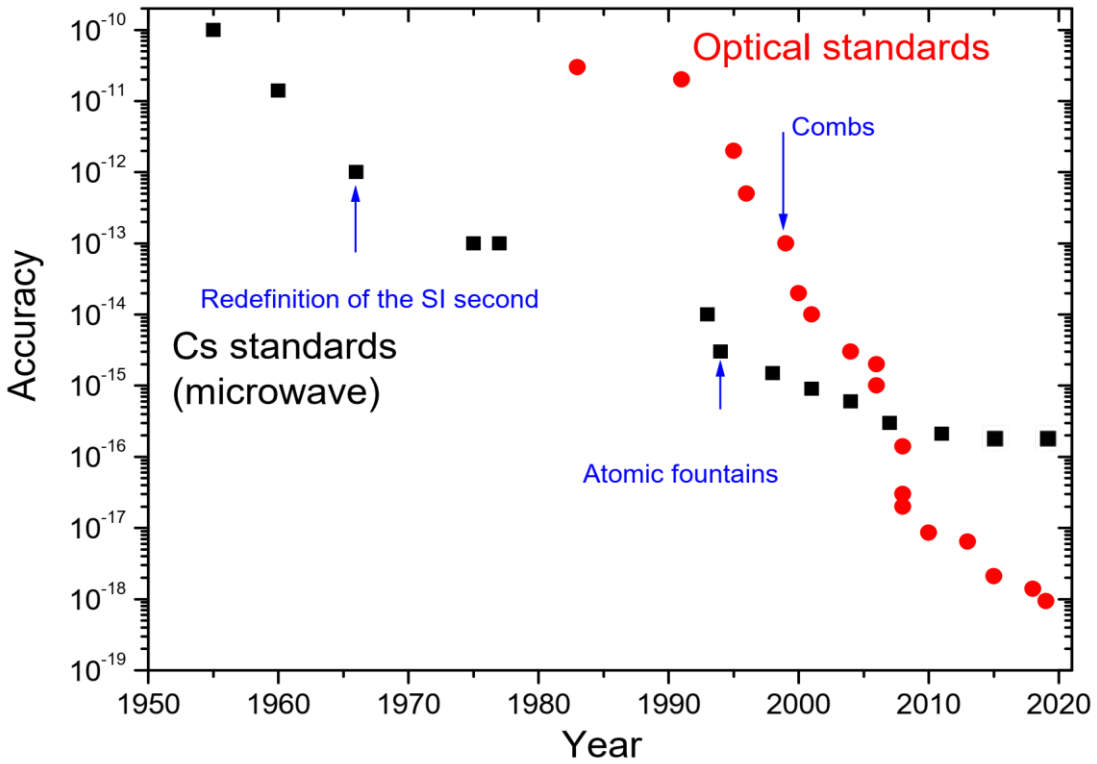
The era of Optical Frequency metrology



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

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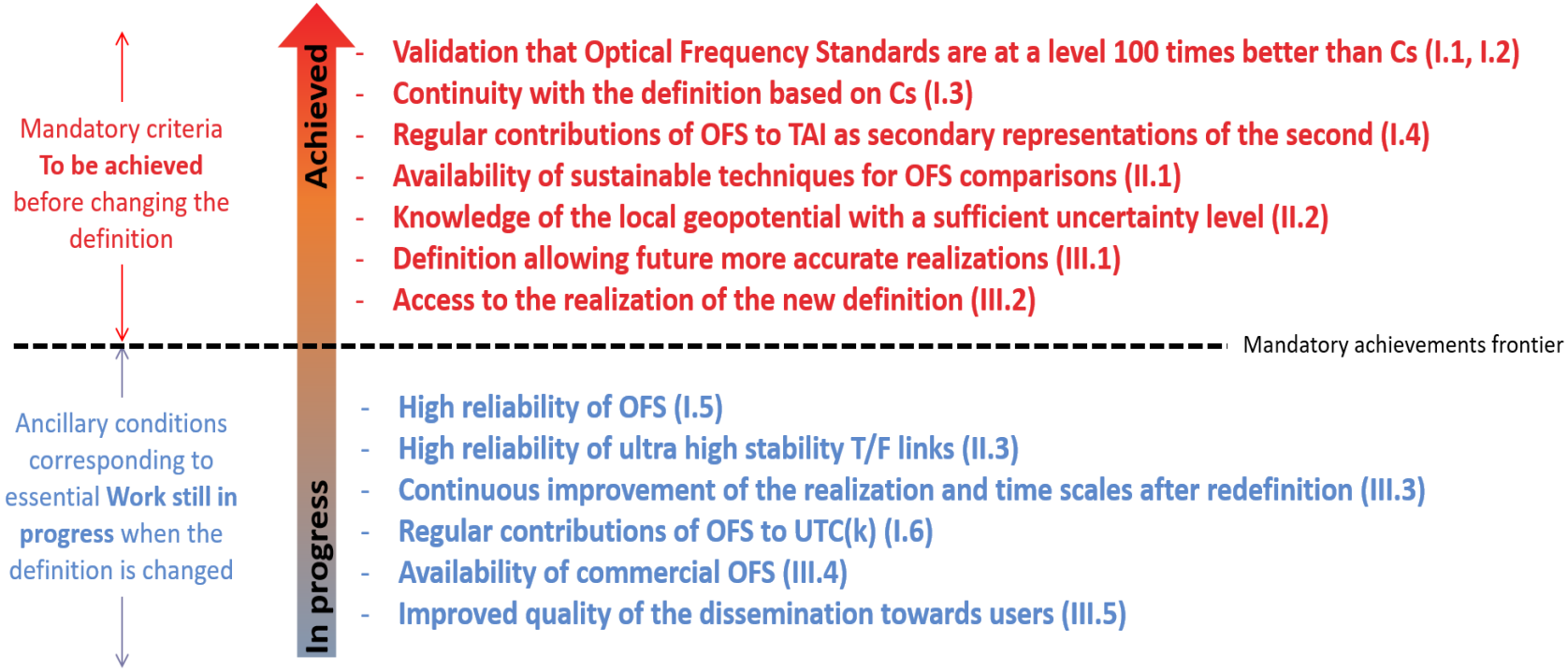
→ Time to change the definition?

Redefinition criteria / conditions



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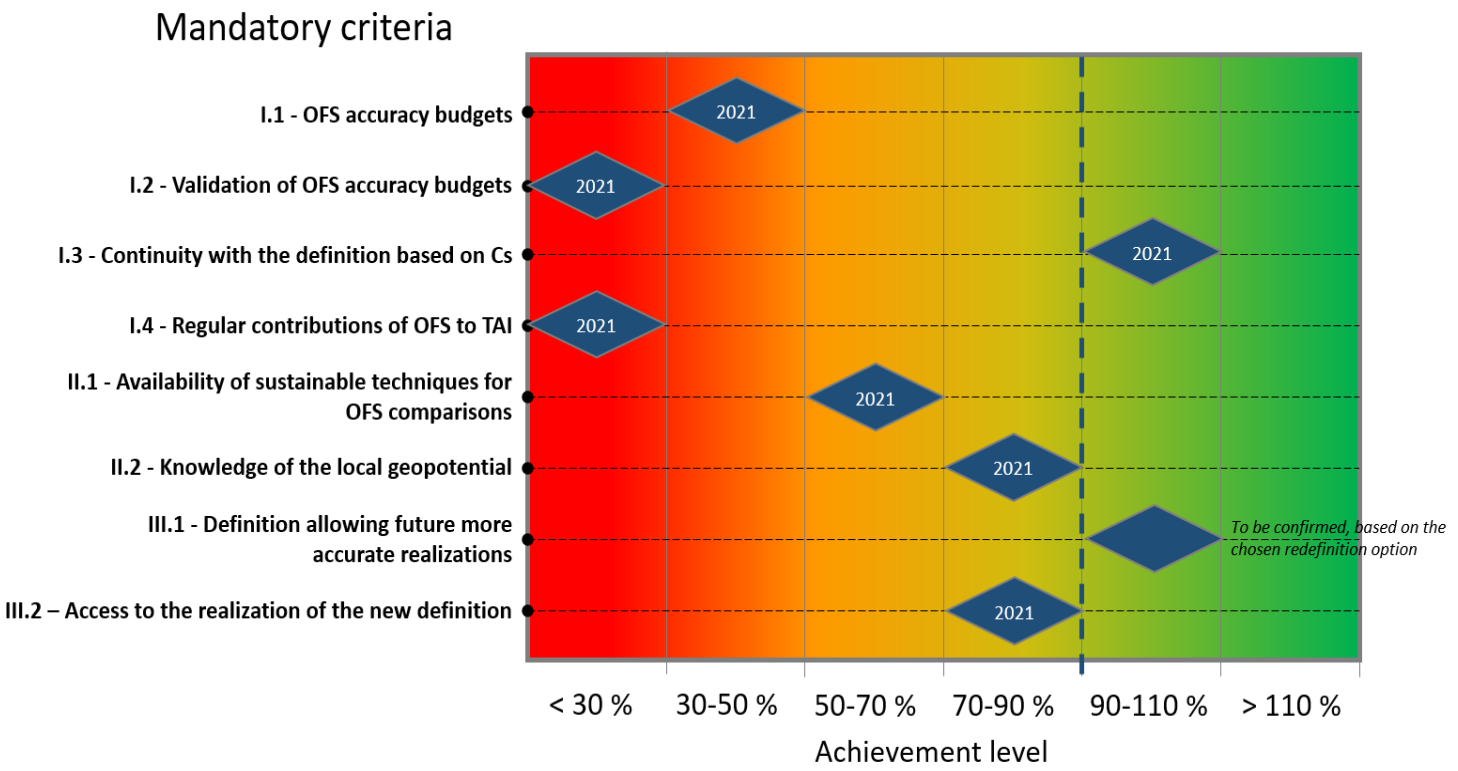
Current fulfilment level of mandatory criteria



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Options envisaged for the new definition

Option 1: New definition based on a **single atomic reference transition** in the optical frequency range.
Secondary representations of the second are provided by frequency standards based on other species. Caesium becomes a secondary representation of the SI second.

Option 2: New definition based on an **ensemble of reference optical frequencies**
Use of the weighted geometric mean of an ensemble of chosen transition frequencies; the weight of each transition is initially fixed and inversely proportional to the squared uncertainty of best standards based on this transition at the time of the definition.
Each transition of the defined ensemble is a representation of the definition, including current Cs reference transition if it is part of the ensemble. → Merging of the concept and use of primary and secondary representation of the second.
The list of chosen transitions and their weights are periodically updated, including transitions already part of the ensemble or not yet part of it, and taking into account the evolution of the uncertainty of the best standards based on the chosen transitions.

Option 3: New definition based on **fixing the value of another fundamental constant**, as it has been done for other SI units. The Mise en Pratique would be based on atomic transition(s), either one as in Option 1 or an ensemble as in Option 2.
→Today, **Option 3 not achievable** as there is not a fundamental physical constant known with the necessary accuracy.

Schedule options for the redefinition of the second

CGPM 2022:

- We have a validated roadmap

AND

- We are able to propose a redefinition option

AND

- We have a clear, achievable and verifiable roadmap to satisfy mandatory criteria by 2025

CGPM 2026:

- Redefinition

CGPM 2022:

- We have a validated roadmap

BUT

- We still have more than one type of possible redefinition, with illustration of (dis)advantages for each type but we have a validated roadmap to reach consensus on which definition type, which radiation(s) by 2025

OR

- The work to fulfill mandatory criteria is unlikely achievable by 2025

CGPM 2026:

- We are able to propose a redefinition option

AND

- We have a clear, achievable and verifiable roadmap to satisfy mandatory criteria by 2029

CGPM 2030:

- Redefinition

CGPM 2022:

- We have a validated roadmap

BUT

- We still have more than one type of possible redefinition, with illustration of (dis)advantages for each type

OR

- The work to fulfill mandatory criteria is long

CGPM 2026:

- We still have more than one type of possible redefinition but we have a validated roadmap to reach consensus by 2025

OR

- The work to fulfill mandatory criteria is unlikely achievable by 2029

CGPM 2030:

- We are able to propose a redefinition option

AND

- We have a clear, achievable and verifiable roadmap to satisfy mandatory criteria by 2033

CGPM 2034:

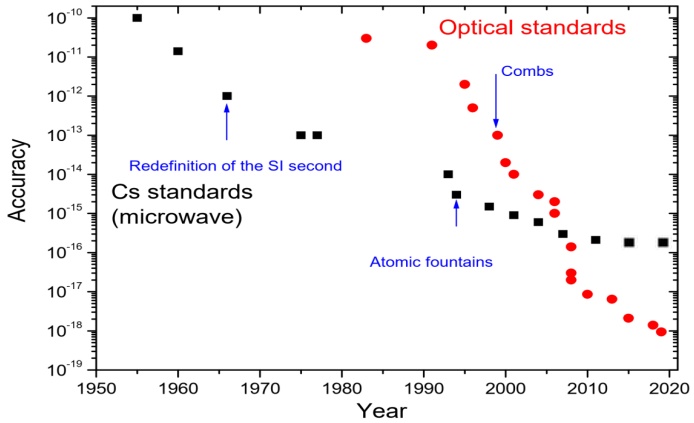
- Redefinition

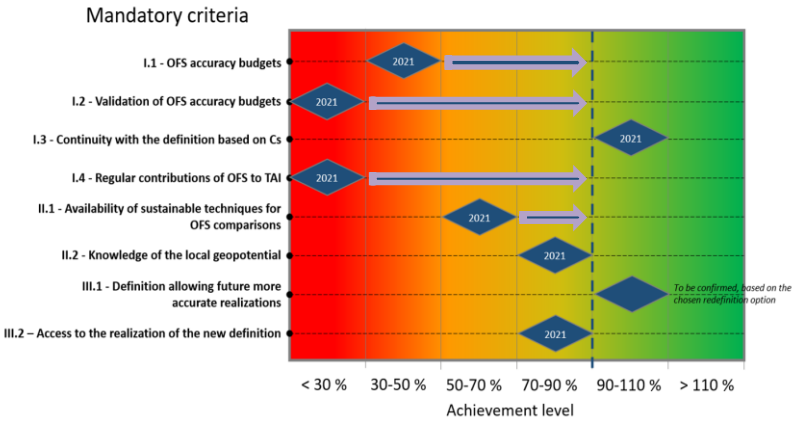
The CCTF has proposed
to the 27th General Conference on Weights and Measures (CGPM) 2022

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

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 agree at its 28th meeting in 2026 on a new definition which could be adopted at the 29th CGPM meeting and implemented 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 (confidence in the fulfilment of mandatory criteria)*





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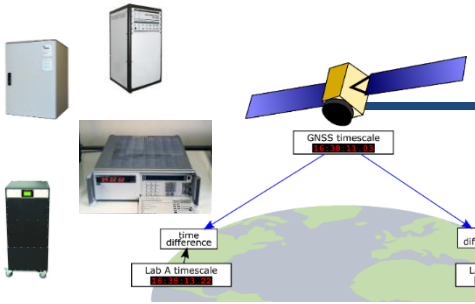
Construction of international time scales



≈ 450 atomic clocks in ~ 85 laboratories

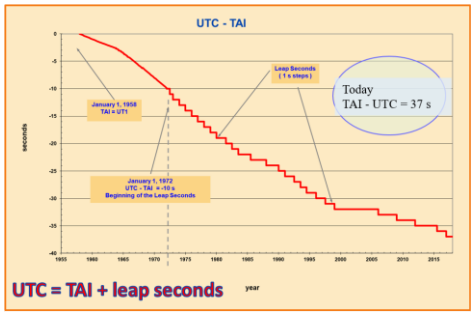
weighted average → **EAL**

Echelle Atomique Libre
freq stability
3×10^{-16}
@ 30-40 days

≈ 10 primary and secondary frequency standards

frequency steering → **TAI**

International Atomic Time
freq accuracy ~10^{-16}



Measurement of Earth's rotation (IERS)

leap seconds → **UTC**

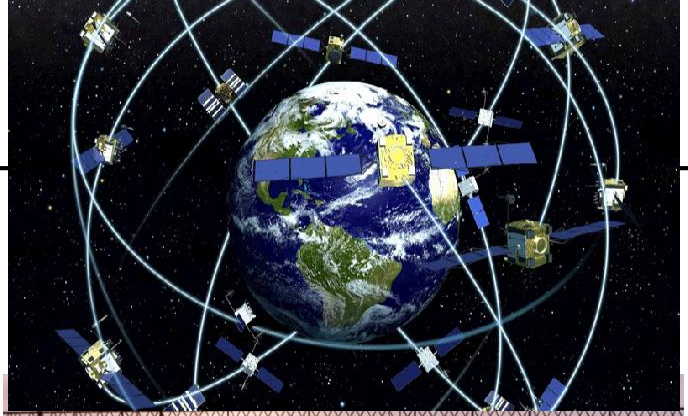
Coordinated Universal Time

[*UTC - UTC(k)*] **BIPM *Circular T***

Current situation

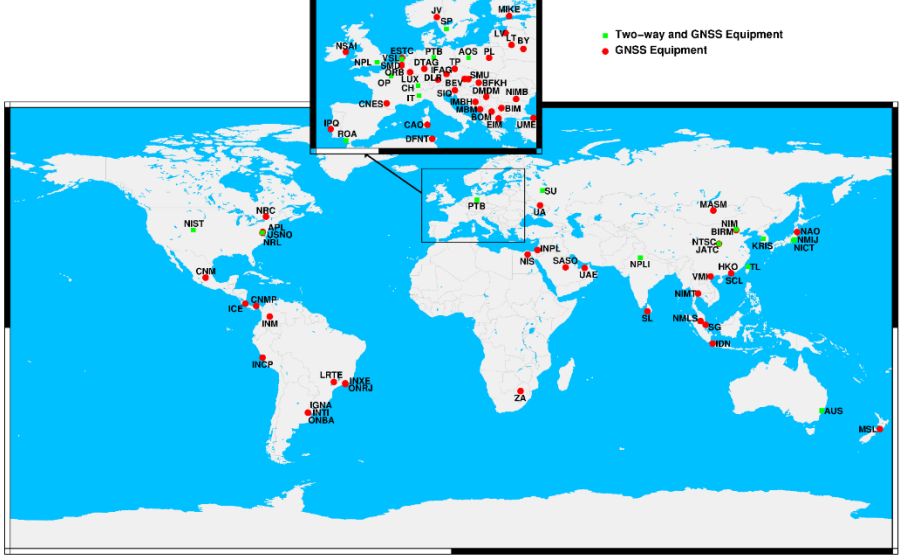
Technological and digital applications which underpin national critical infrastructures are based on an overall synchronization

The main requirements for the common time scale is that it be continuous, monotonic, reliable, and easily available.



The Coordinated Universal Time UTC

under the authority of the CGPM,
computed at the BIPM,
and realized in real-time by ~ 85 NMIs
in the world



- can support the world digital networks and satellite systems
- can support the resilience of critical national infrastructure to avoid the risk of failure due to multiple synchronization references
- can be recognized as unique world reference time scale
- can ensure the central role to BIPM and NMIs in the worldwide timekeeping

→ if it is continuous

Currently UTC is maintained in close agreement with the irregular rotation of the Earth by ad hoc corrections

which are not implemented by

- most of the GNSSs,
- the digital network giants as GAFA and Alibaba,
- the most diffused Internet time synchronisation protocols as NTP and PTP
- Google smear is proposed as new international standard

If UTC is not modernized it will become marginal and less universal. This is a key matter for the future of time metrology

A GNSS system time, which is continuous and easily accessible, is already considered as source of time and frequency reference and could become, *de facto,* the international standard time

The role of all NMIs as source of traceability to national and international metrological standards and synchronisation is at risk.

Solution for a continuous UTC

- **Increase the tolerance in|UT1 - UTC| to a new limit** (e.g. 1 min reached after 1 century or 1 hr reached after 5000 yrs) or to an unlimited value (= the difference UT1 – UTC will be let growing with no limit) ; *It seems preferable not to fix a new tolerance limit (e.g. 60 s or 1 hour) to avoid a decision to be applied in 100-5000 yrs.*

- **Solution and date of application: by or before 2035** (best trade-off taking into account technical / legal issues).

- **UTC remains linked to UT1**, the Earth's rotation angle, the origin is the reference meridian of Greenwich. UTC is approximately UT1 within the 15 min of seasonal day variation for centuries. For the general public this change is a "no event"

- **Pursue the activities on the precise determination and distribution of UT1-UTC**
  - IERS and NASA web sites with microsecond uncertainty
  - GNSSs, with some update, will still disseminate UT1-UTC
  - Radio stations may stop the transmission of DUT1 (as DCF 77 did)

The CCTF has proposed

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

the draft Resolution D – On the use and future development of UTC

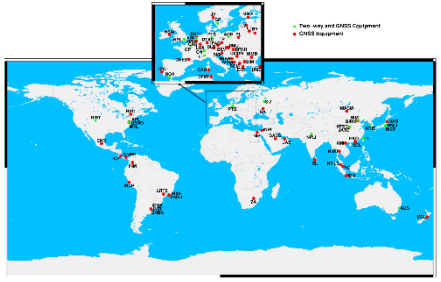
recognizing *that the use of* ***UTC as the unique reference time scale for all applications****, including advanced digital networks and satellite systems, calls for its clear and unambiguous specification as a* ***time scale monotonically increasing, without discontinuities****, and with well understood traceability chains,*

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

Please discuss with your timing experts and vote

and promote opportunities in your countries to inform on this challenge

to ensure UTC remains the best metrological standard



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Thank you for your attention