The Redefinition of the Second and upcoming changes in timekeeping

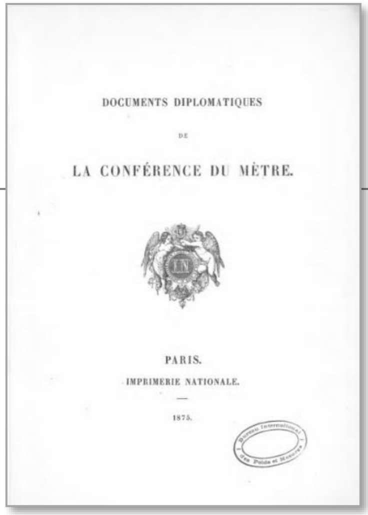
Patrizia Tavella   BIPM, CCTF Executive secretary

Work of:
CCTF Task Force on the Roadmap towards the redefinition of the second
Several CCTF Working Groups
BIPM Time Department

Bureau International des Poids et Mesures

CCTF

The Bureau International des Poids et Mesures - BIPM an international organization



Established in 1875 when 17 States signed the Metre Convention, now with 64 Member States and 36 Associate States and Economies **working together to promote and advance the global comparability of measurements**

CGPM – Conférence générale des poids et mesures

Official representatives of Member States.

CIPM – Comité international des poids et mesures

Eighteen individuals of different nationalities elected by the CGPM.

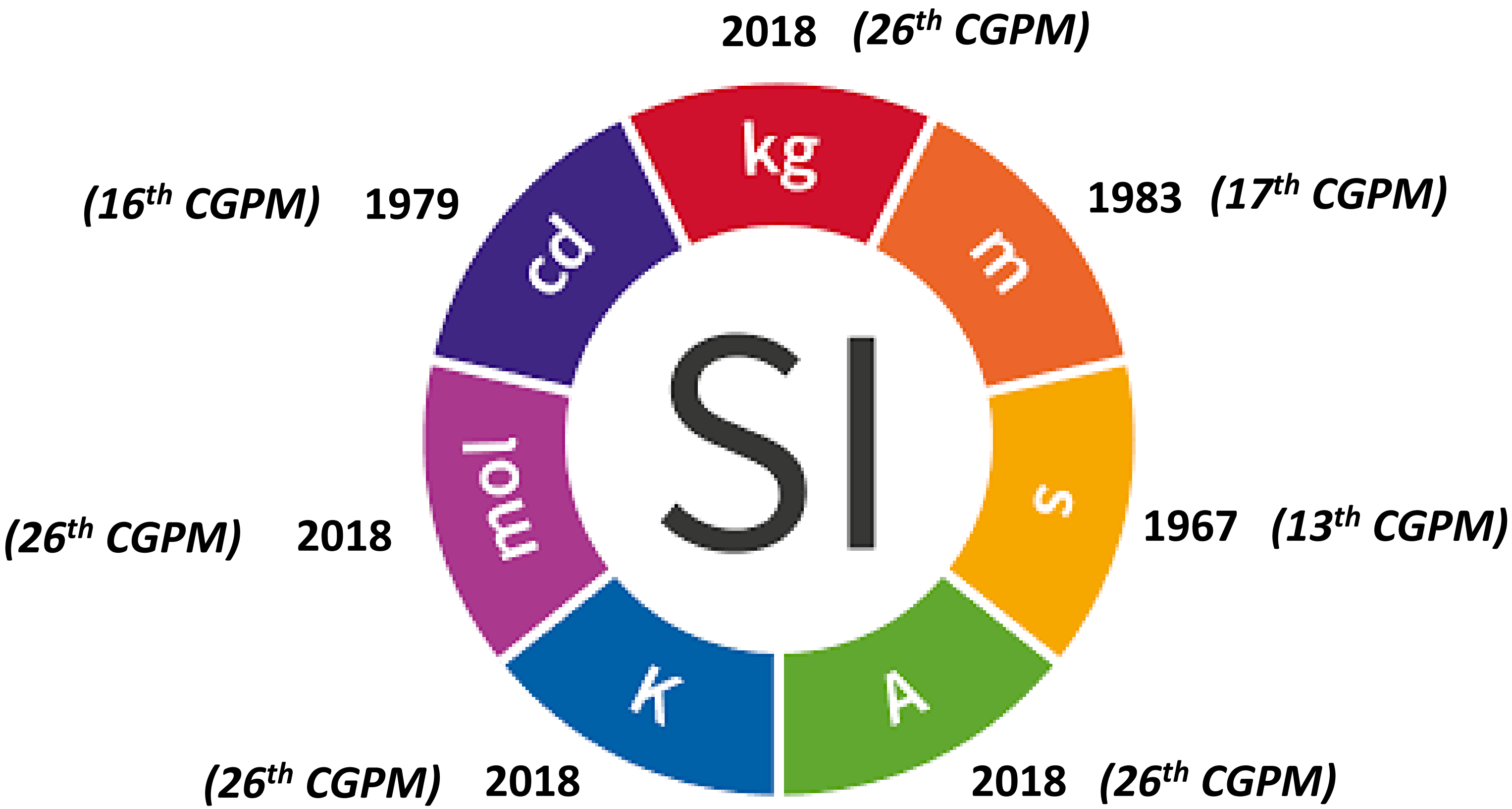
Scientific and technical secretariat (in Sèvres)

- *International coordination and liaison*
- *Technical coordination – laboratories*
- *Capacity building*
- *Home of the* **Coordinated Universal Time (UTC)**

Consultative Committees (CCs)

CCAUV – Acoustics, US & Vibration
CCEM – Electricity & Magnetism
CCL – Length
CCM – Mass and related quantities
CCPR – Photometry & Radiometry
CCQM – Amount of substance
CCRI – Ionizing Radiation
CCT – Thermometry
CCTF – Time & Frequency
CCU - Units

The International System of Units



Definitions of the SI unit of time

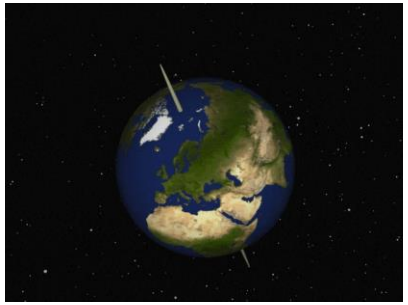
Astronomy - observation of the angle/phase of a celestial movement

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

→ **until 1960 : the fraction 1/86 400 of the mean solar day**

→ **1960 to 1967 : the fraction 1/31,556,925.9747 of the tropical year 1900**

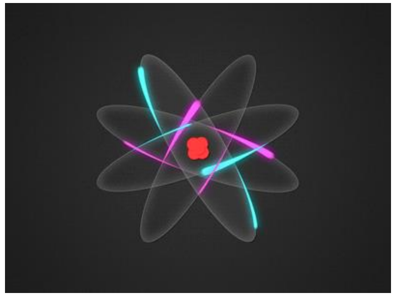
1 tropical year = 365,2422 solar days



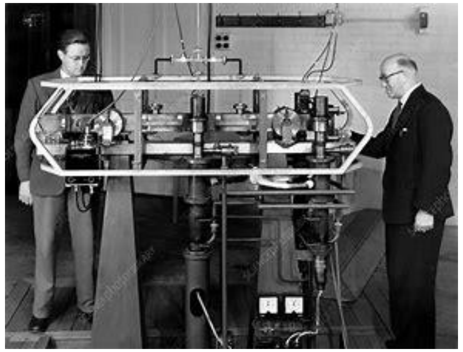
Quantum physics – generating a periodic process with well know frequency

→ **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

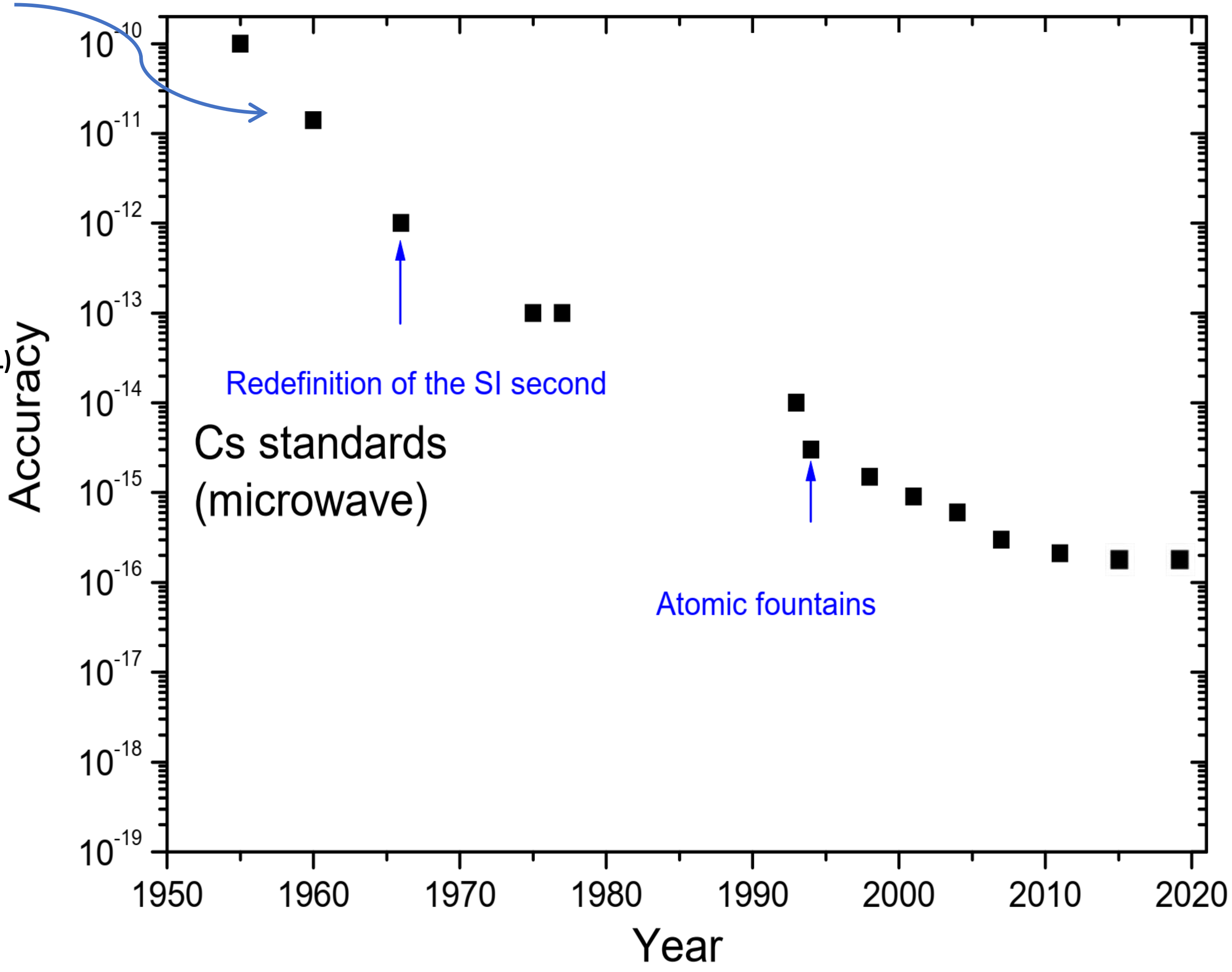


Realization of the SI second with primary Cs frequency standards



First Cs frequency standard (Photo: NPL)

Cs atomic beam frequency standard (Photo: PTB)

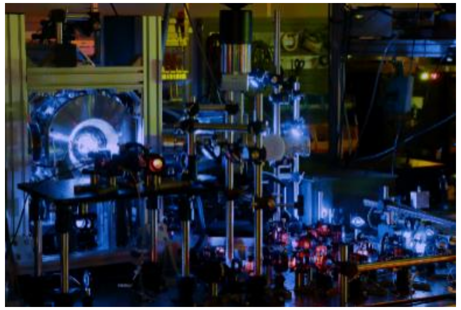


Cs fountain (Photo: INRIM)

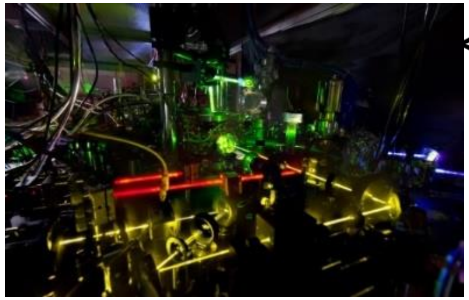
Cs fountain accuracy ~ 10^{-16}

Cs fountain (Photo: NIM)

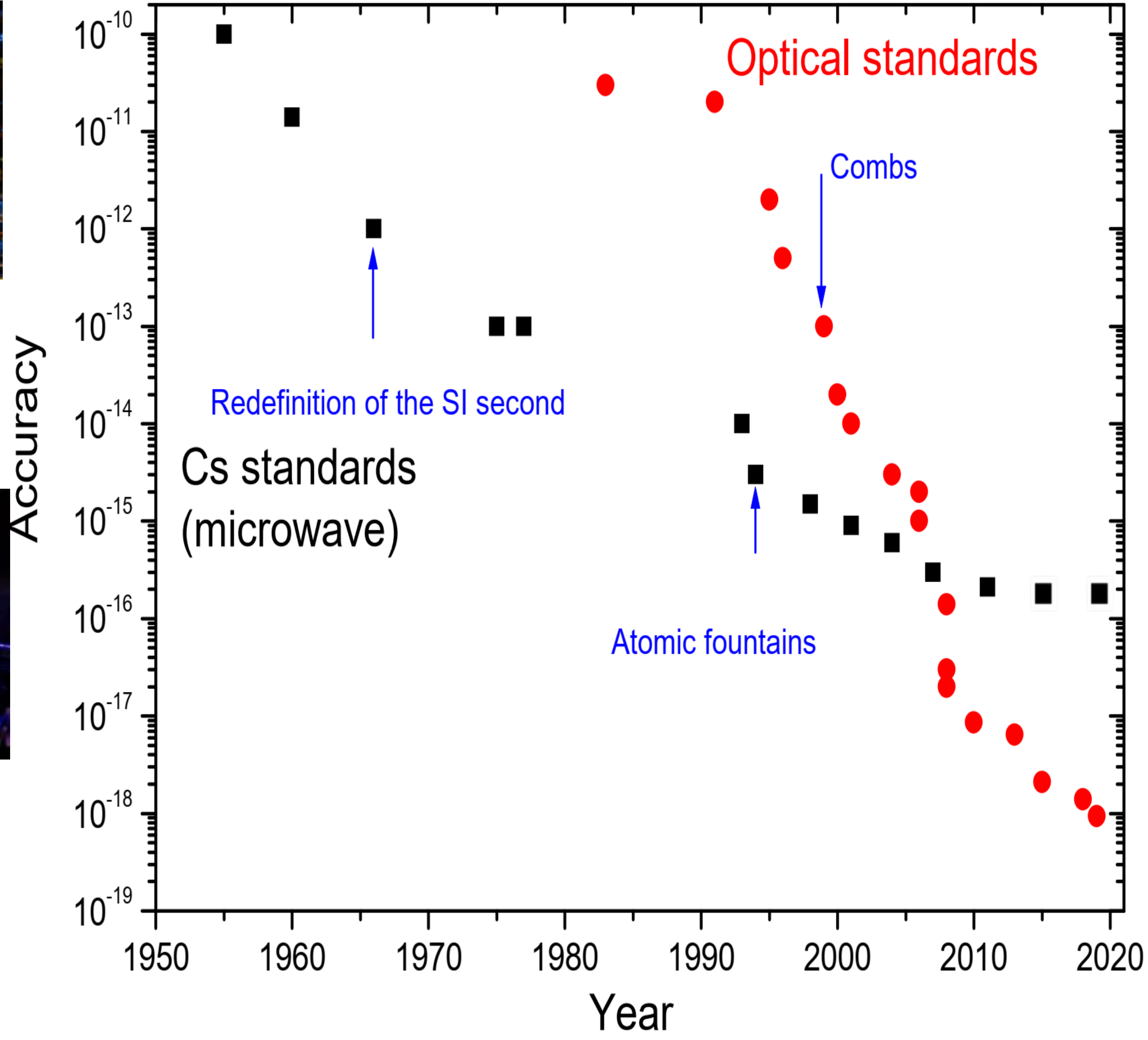
Today the second is defined on a cesium radiation



Sr lattice Clock (Photo: NICT)



Yb Lattice Clock (Photo: NIST)



Optical Frequency Standards (Sr, Yb, Yb+, Al+, Ca+, …) at 10^{-18} relative accuracy
(0.1 picosecond / day
3 nanosecond / 100 years)

are surpassing the accuracy obtainable with Cesium clocks

→ **Time to change the definition of the second?**

→ **What do we need?**

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

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.

Working towards CGPM 2026

We need a consensus on:

1. **which definition option and which radiation(s)**

2. **clear achievable and verifiable roadmap to satisfy mandatory criteria by 2029**

Summary of options for the redefinition

- Option 1:

$$\nu_{\mathrm{Xv}} = N\ \mathrm{Hz}$$

  - Example

$$\nu_{^{87}\mathrm{Sr}} = 429\,228\,004\,229\,872.99\ \mathrm{Hz}$$

- Option 2.1:

$$\prod_i \nu_i^{w_i} = N\ \mathrm{Hz}, \qquad \left(\text{with} \sum_i w_i = 1\right)$$

static definition

  - Example

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

- Option 2.2:

$$\prod_i \nu_i^{w_i} = N\ \mathrm{Hz}, \qquad \left(\text{with} \sum_i w_i = 1\right)$$

dynamic definition

CIPM can update w_i, N and the ensemble of chosen transitions following a set of predefined rules

Opt 2.2 is initially identical to opt 2.1, and include opt 1 as special case

- Option 3:

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

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

  - Example:

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

Criteria / conditions to change definition

Mandatory criteria
To be achieved
before changing the definition

Achieved

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

Mandatory achievements frontier

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

In progress

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

Criteria / conditions to change definition

Frequency standards & contribution to atomic time scales

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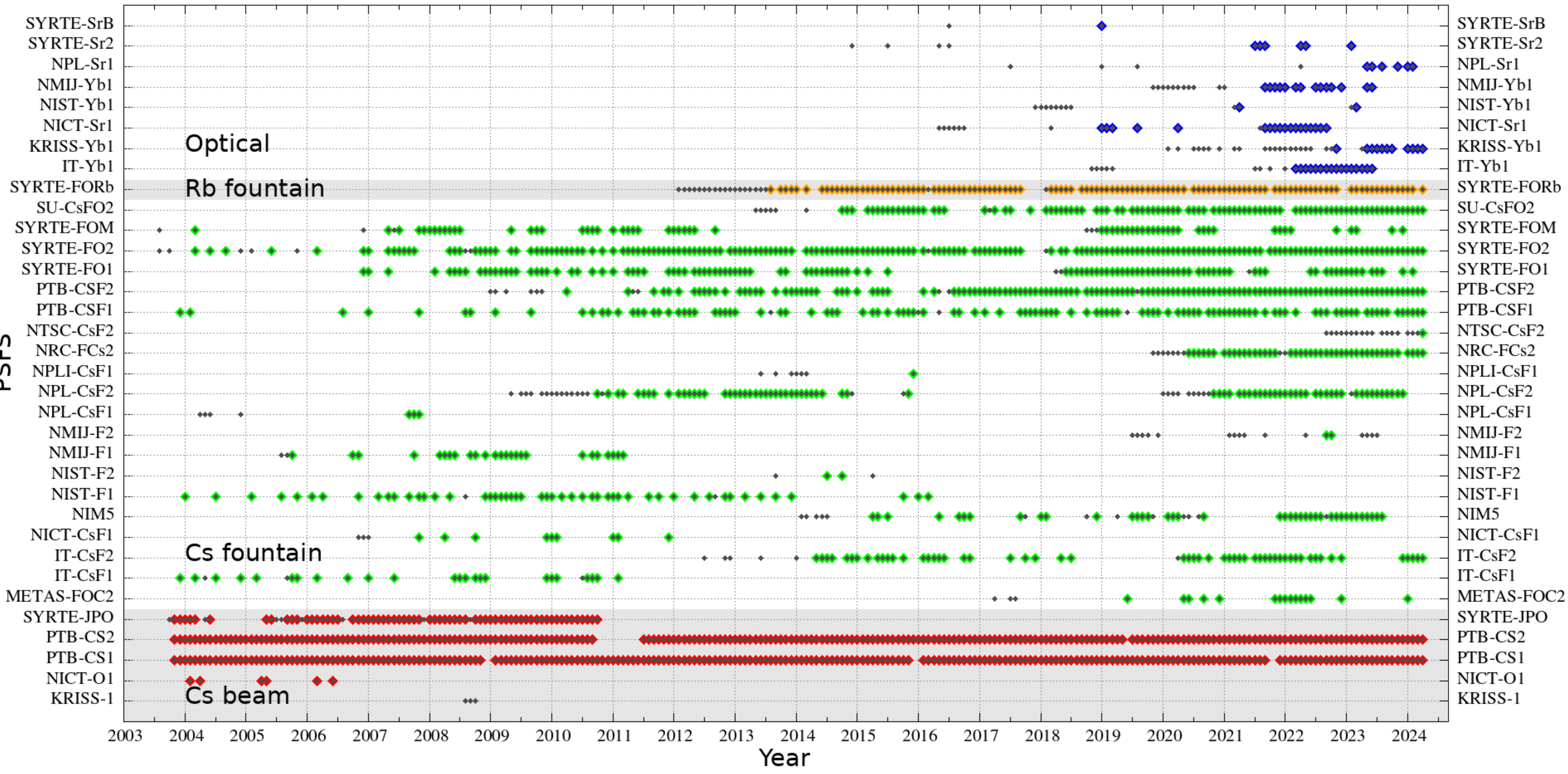
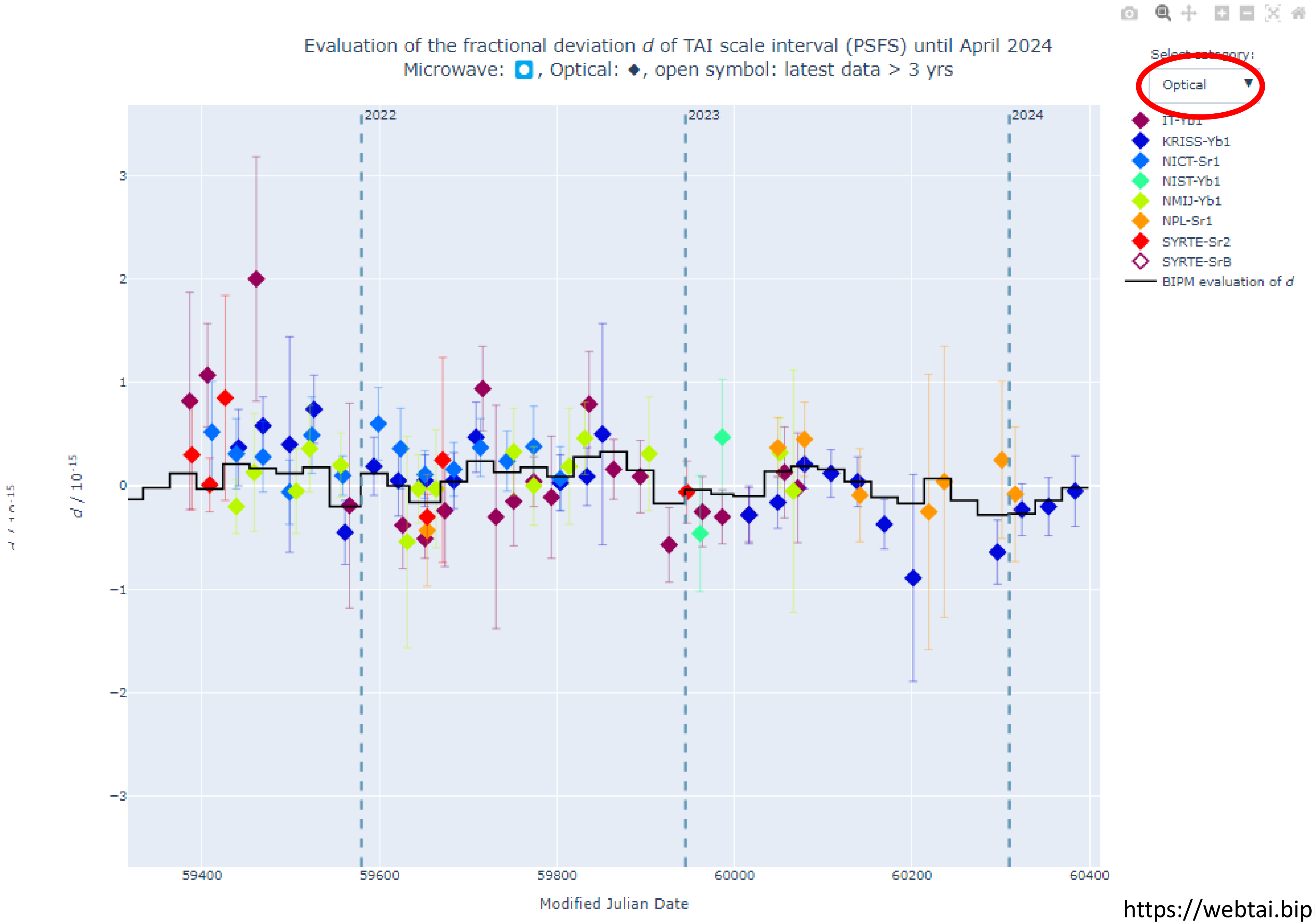
- **Regular contributions of optical clocks to UTC(k)**
- Availability of commercial optical clocks (III.4)
- Improved quality of the dissemination towards users (III.5)

Contribution from Primary and Secondary Frequency Standards to UTC

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



Frac Fractional deviation *d* of TAI scale interval (PSFS)



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

Criteria / conditions to change definition

TF comparison and dissemination

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How to compare optical clocks at distance?

- At the 10^{-18} accuracy level

optical fibers are very promising

Presently limited to (sub) continental links

"portable" optical clocks are under development

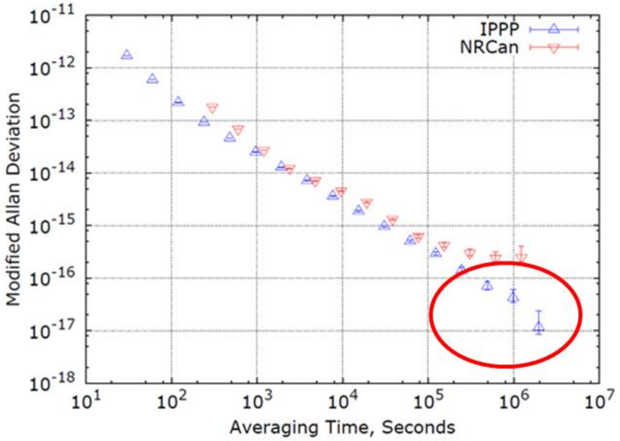
- At the 10^{-17} accuracy level

Several techniques are possible candidates, can these do better?

GNSS Integer PPP

< 1×10^{-16} after several days (integration time)

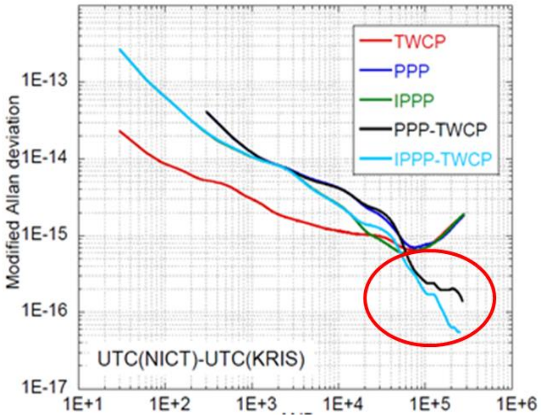
Readily available, no constraint



Satellite Two way Carrier Phase

< 1×10^{-16} after one day?

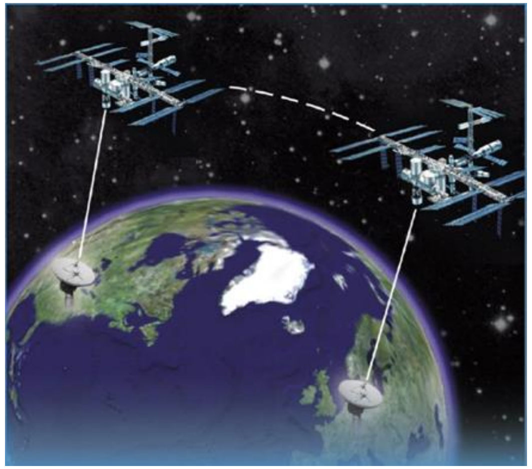
Available, with constraints



ACES microwave link

1×10^{-17} after one/several days?

To be launched > 2024



With atomic clocks, the relativity is common routine

Travelling clock are slowing down

Clock at high altitude are going faster

The relative effect is 10^{-13} / km

3 microsec / year for one km in altitude

On board Global Navigation Satellite System at 20000 km

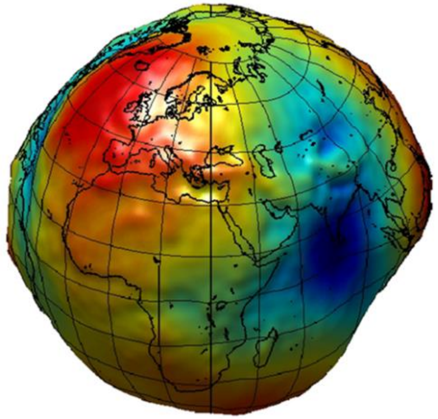
The effect is about 4 10^{-10} which means

40 microseconds in a day

corresponding to about 10 km error in positioning in one day

Relativistic geodesy

To compare two frequency standards at a distance, one has to account for their relativistic frequency shift



$d\tau_A / d\tau_B \approx 1 + (W_B - W_A)/c^2$ **where W is the gravity potential**

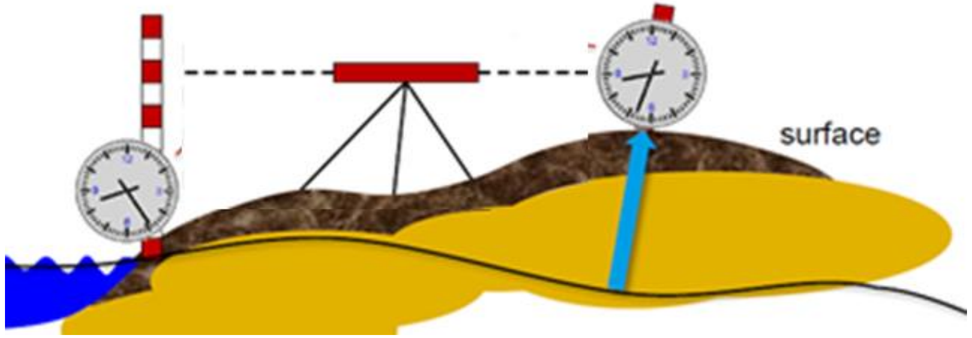
- The relative effect is 10^{-13} / km
- The relative effect is 10^{-16} / m
- At the 10^{-18} accuracy level one needs to

know the clocks height with 1 cm accuracy

Conversely one can directly measure the geopotential (height) difference between any two clocks (1 cm $\approx 1\times10^{-18}$) if

•The clocks are accurate to 10^{-18}

•Their frequency difference can be measured to 10^{-18}



The clock is measuring the geopotential or the knowledge of the geopotential is used to correct the clock? Shall we define time scale in space?

Criteria / conditions to change definition

Acceptability of the new definition

Achieved

Mandatory criteria
To be achieved
before changing the definition

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Mandatory achievements frontier

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

- High reliability of optical frequency standards
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In progress

Fulfilment level of mandatory criteria (2023)

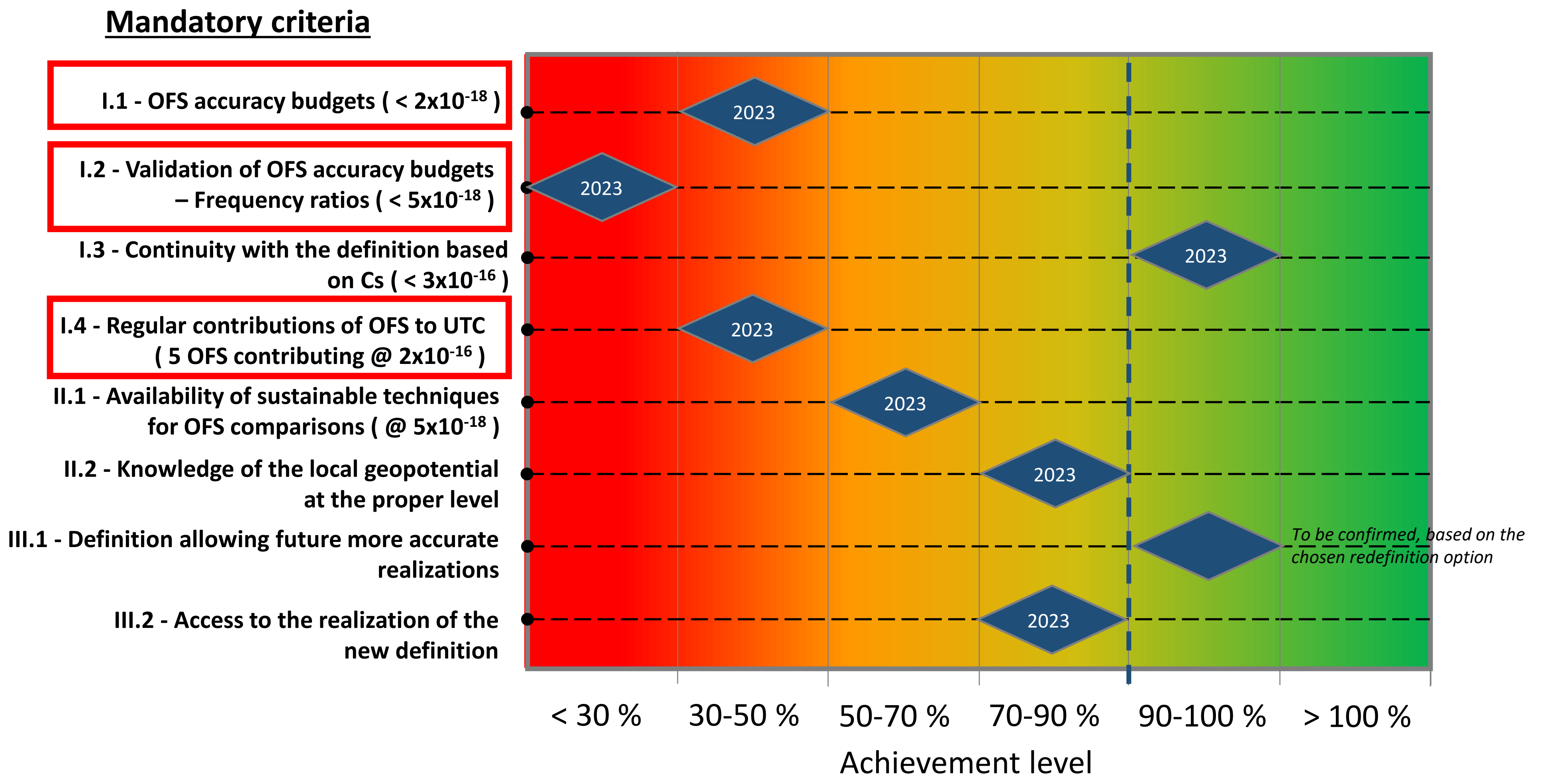
OFS = Optical Frequency Standard
UTC = Coordinated Universal Time

Great effort in progress for:

more optical frequency standards in operation

more comparisons of distant optical frequency standards

more high accuracy contributions to the Coordinated Universal Time



Still a long way to the redefinition of the second

Roadmap towards the redefinition of the second

The Task Force is preparing several documents to illustrate

- the possible redefinition options,
- the status of the redefinition candidates,
- the fulfillment of the mandatory criteria,
- and the educational activities.

Stay tuned, in 2030 (2034?) we may change the definition of the second

Some documents are public and accessible
https://www.bipm.org/en/redefinition-second

Roadmap to the redefinition of the second

The CCTF is currently working towards an update of the definition of the second, in accordance with the significant improvements in atomic clock designs that have occured in the recent years.

This web page collates some of the general and publicly accessible information associated with the process.

The time and frequency community is highly engaged in the long journey that will eventually lead to the redefinition of the second, possibly in 2030. We will update and add content to this page in the coming years. Please revisit this page regularly to stay up to date.

Frequently Asked Questions concerning the Redefinition of the Second

CCTF Task Force on Updating the Roadmap for the redefinition of the second

Roadmap towards the redefinition of the second

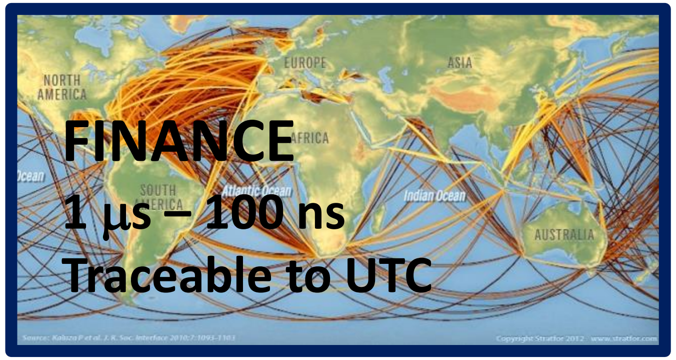
Metrologia (2024) **61** 012001
Noël Dimarcq et al.

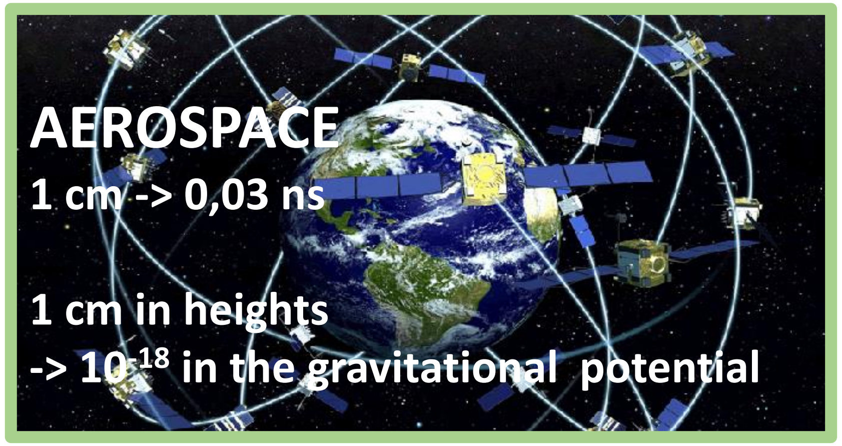
What time is it? What is UTC?

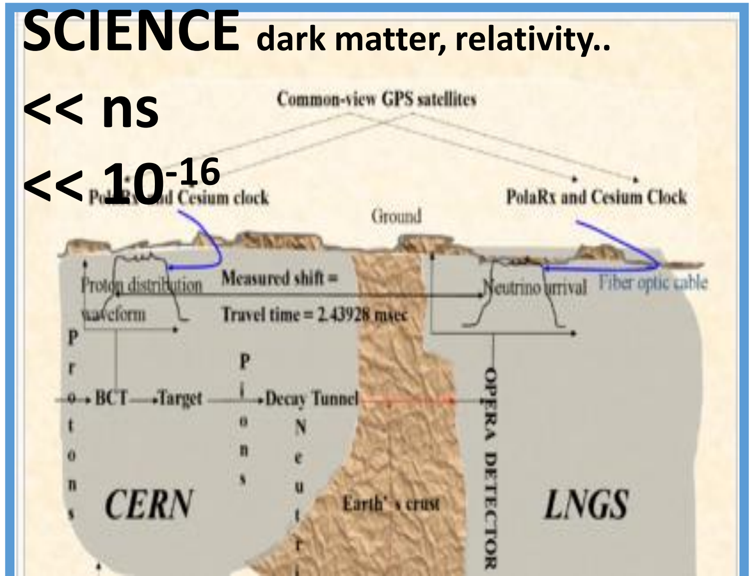
The Bureau International des Poids et Mesures (BIPM) maintains and coordinates international measurement standards

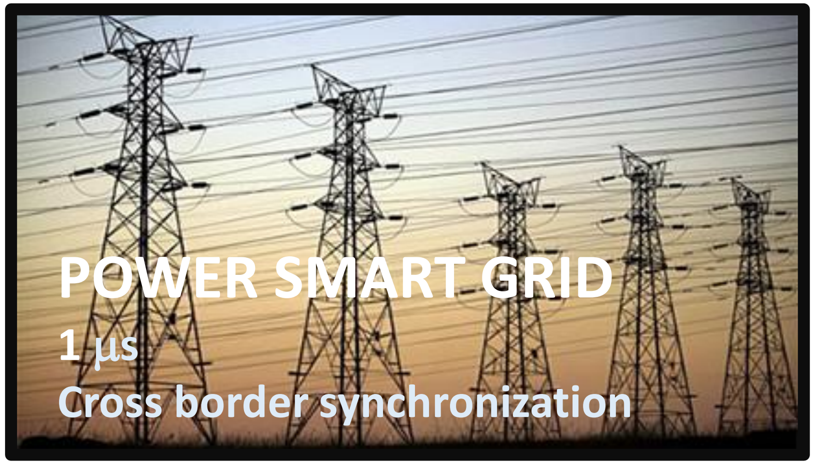
and compute the Coordinated Universal Time (UTC)

In each country a local realization of UTC is the basis of legal time and synchronization

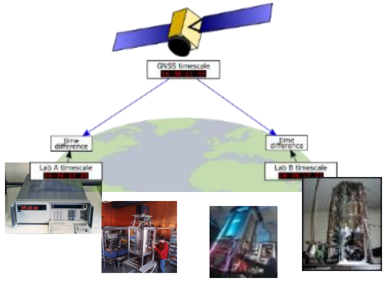








Construction of the Coordinated Universal Time



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

≈ 450 atomic clocks
≈ 15 primary frequency standards

in ~ 85 laboratories

TAI

International Atomic Time

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

leap seconds

UTC

Coordinated Universal Time

|UT1 – UTC| < 1 s

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

UTC definitive results each month

UTC Rapid solution each week

UTC(k) are national realizations in real time

About 450 Clocks participating in TAI

- Cesium clocks 55%
- Hydrogen masers 35%
- Others 10%

PTB-CS1
PTB-CS2

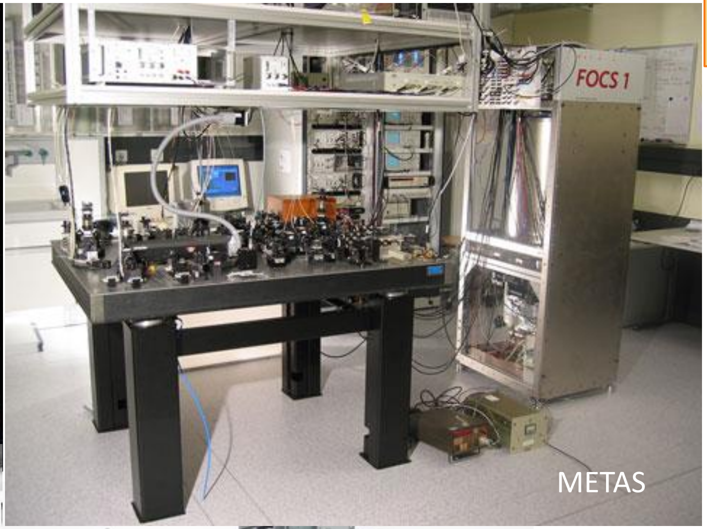
NTSC and USNO Rubidium Fountain

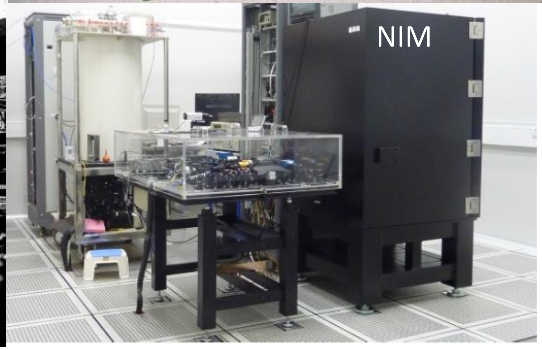
Primary frequency standards

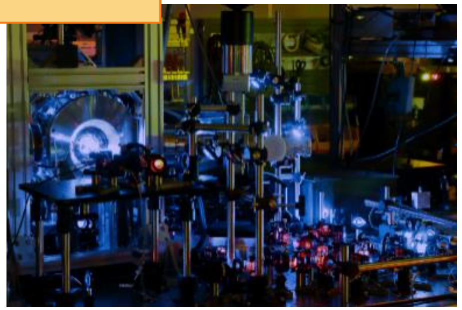
About 10 laboratories operate primary frequency standards. Their uncertainty can be evaluated a priori by examining the different effects perturbing the Cesium atom

The uncertainty of Caesium primary fountains can reach 10^{-16}

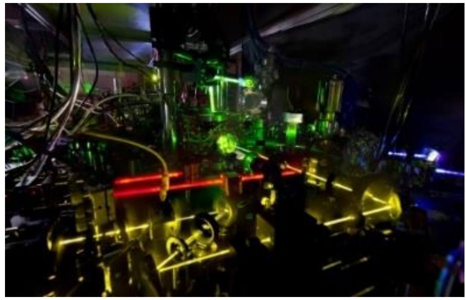
3 nanoseconds accumulated in ~~1~~ 100 year



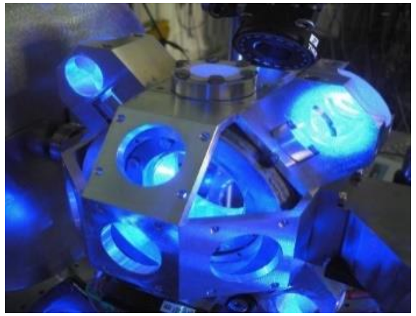




Sr lattice Clock (Photo: NICT)



Yb Lattice Clock (Photo: NIST)

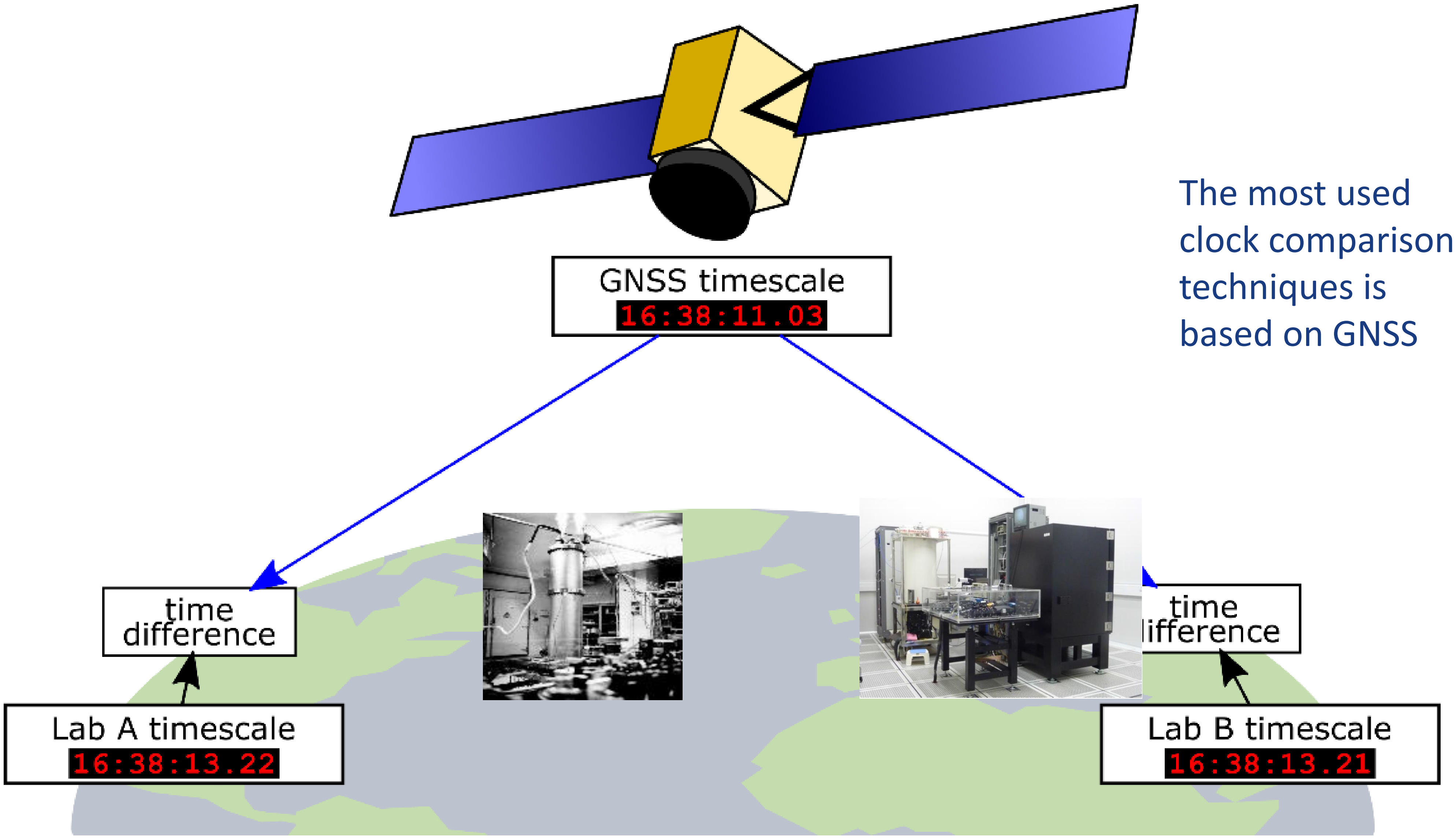


Sr Clock (Photo: LNE–SYRTE)

Progress in the construction of optical frequency standards allows now 10^{-18} accuracy

This is why we are working on the redefinition of the second

Clocks need to be compared

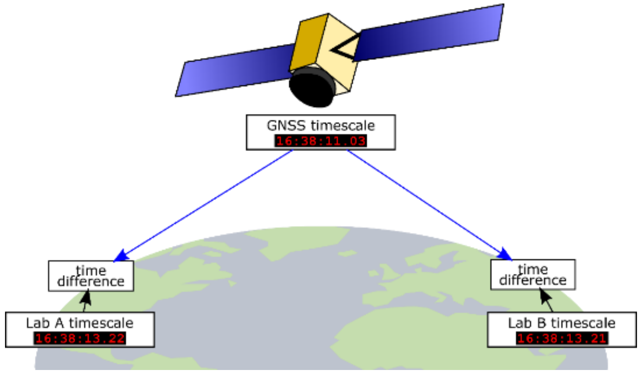


The most used clock comparison techniques is based on GNSS

Clocks in different laboratories are compared by suitable **time and frequency transfer techniques**

Global Navigation Satellite Systems (GNSS)

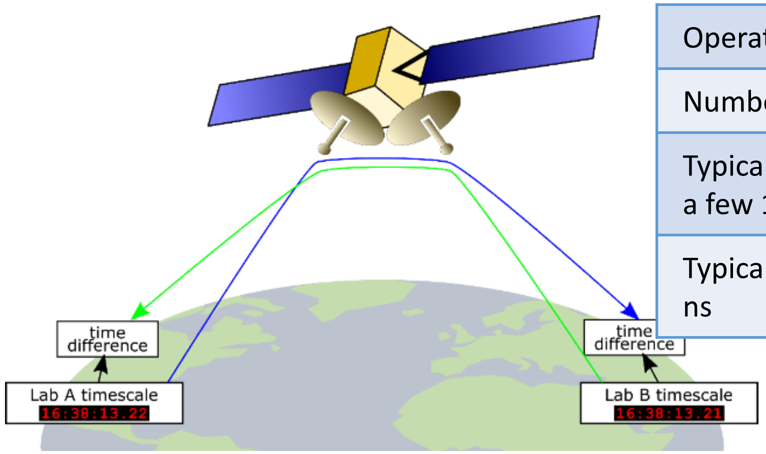
GNSS are based on time broadcasting from satellites to ground receivers (one-way time transfer). Distant labs equipped with GNSS receivers periodically compare their clocks to the broadcasted time and send the result to the BIPM.
Typical algorithms are All in View, Common View, and Precise Point Positioning



Operational since ~ 1980
Number of links : all contributing laboratories
Typical freq. transfer accuracy @1d : a few 10^{-15}
Typical time transfer accuracy : a few ns

Two-Way Satellite Time & Freq. Transfer (TWSTFT)

dedicated ground terminals simultaneously receive and transmit time transfer signals (two-way time transfer) on geostationary telecom satellites.
Two-way method cancels out (at first order) the propagation time of the signal.



Operational since ~2000
Number of links : 18
Typical freq. transfer accuracy @1d : a few 10-15
Typical time transfer accuracy : ≳ 1 ns

Progress in GNSS measures

GPS+ GLONASS + Beidou + Galileo
IPPP : Precise Point Positioning with integer ambiguity resolution

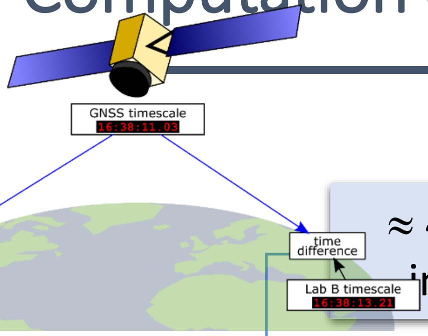
Progress in TWSTFT

Software Designed Radio and TWSTFT Carrier Phase

In development : Optical Fiber links

A growing number of UTC laboratories are gaining access to fiber links dedicated to time and frequency. Although few of them are currently interconnected by operational, high-duty cycle links, this number is expected to grow quickly during the next decade.

Computation of UTC (monthly) at the BIPM

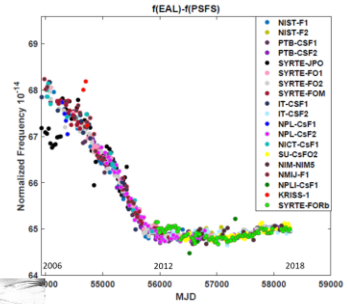


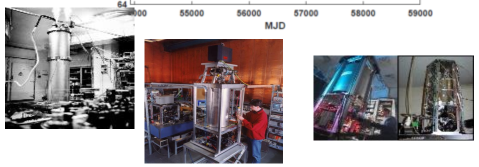
≈ 450 atomic clocks in 85 laboratories

weighted average

EAL

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





≈ 10-15 primary and secondary frequency standards

frequency steering

TAI

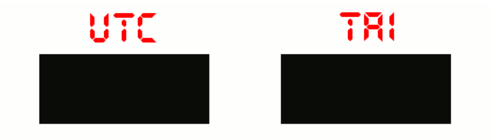
International Atomic Time
freq accuracy ~10^{-16}

Coordinated Universal Time UTC is
in agreement with the rotational angle of the Earth UT1

Timekeeping is related to the rotation of the Earth.

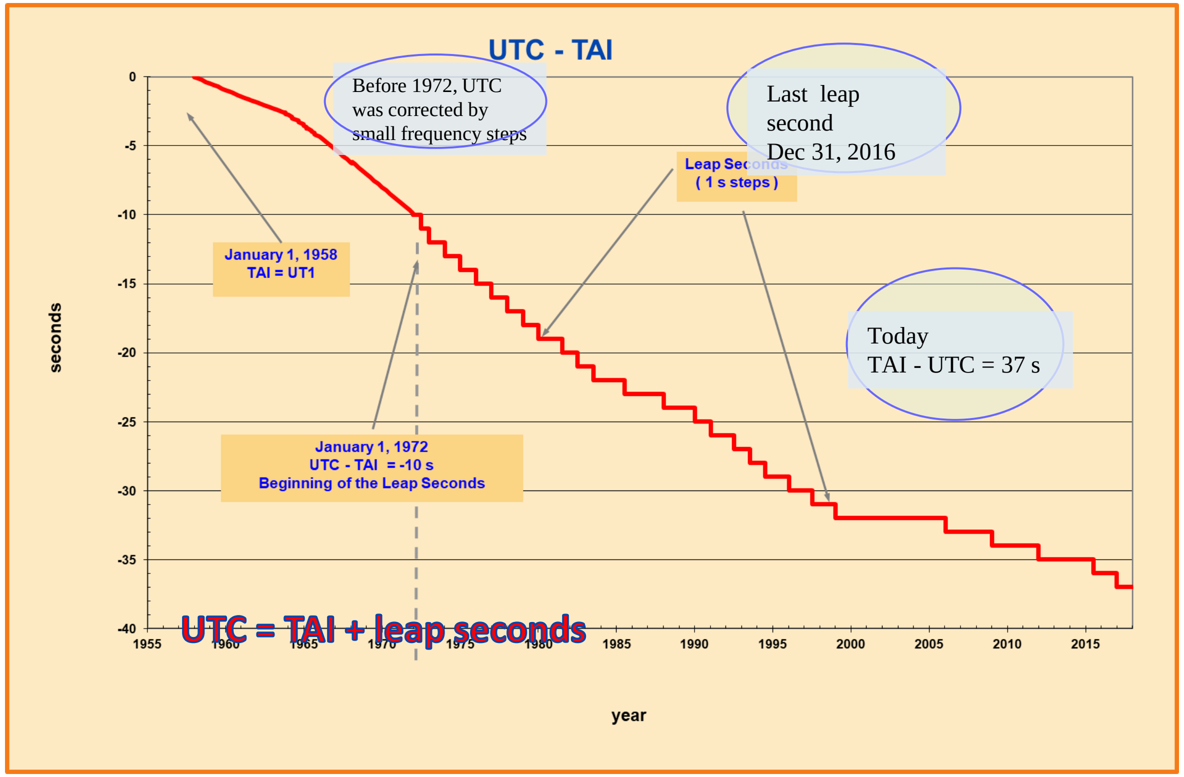
The real time timekeeping is based on atomic clocks and, since 1972, UTC is obtained from the International Atomic Time (TAI) plus leap seconds.

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.



$$|UTC - UT1| < 1 \text{ second}$$

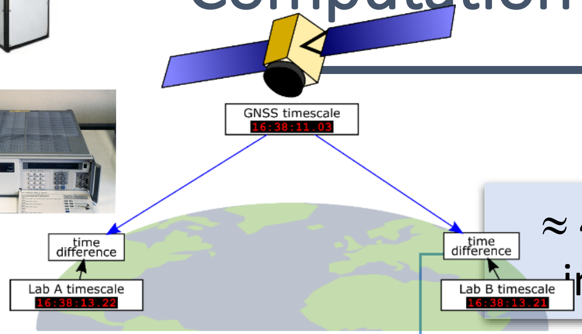
$$UTC = TAI + n \text{ seconds}$$

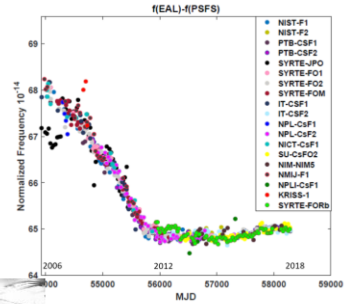


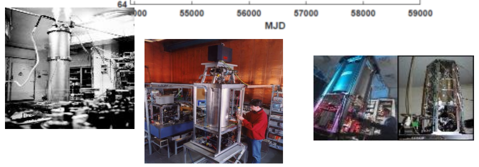
23:59:59
23:59:60
00:00:00

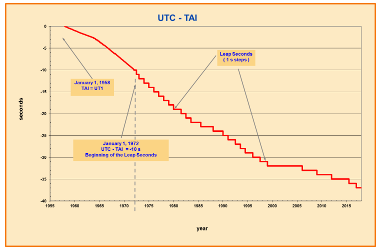
The process to insert the leap second and the code to transmit DUT1= UT1-UTC are described in Rec ITU-R TF 460-6

Computation of UTC (monthly) at the BIPM









≈ 450 atomic clocks in 80 laboratories — weighted average → **EAL**

Echelle Atomique Libre
freq stability
3 x 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***

The results are the differences UTC- UTC(k) of the previous month (or week with the rapid UTC solution)

Bureau International des Poids et Mesures

CIRCULAR T 435 ISSN 1143-1393

2024 APRIL 12, 13h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
THE INTERGOVERNMENTAL ORGANIZATION ESTABLISHED BY THE METRE CONVENTION
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T "
available at https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf

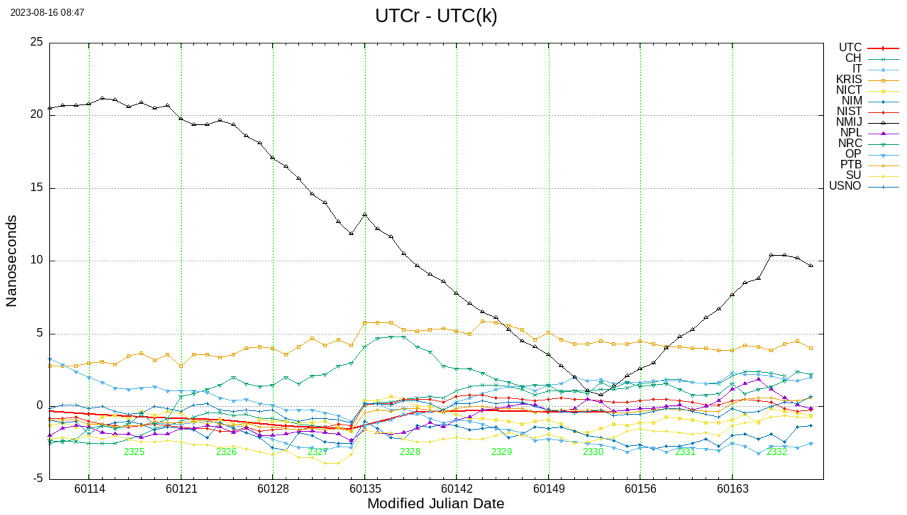
1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2017 January 1, 0h UTC, *TAI-UTC* = 37 s.

Date 2024 0h UTC		FEB 29	MAR 5	MAR 10	MAR 15	MAR 20	MAR 25	MAR 30	Uncertainty/ns			Notes
	MJD	60369	60374	60379	60384	60389	60394	60399	u_A	u_B	u	
Laboratory *k*		[*UTC-UTC*(*k*)]/ns										
AGGO	(La Plata)	752.2	756.6	755.3	750.1	742.3	738.6	729.2	0.7	3.0	3.1	
AOS	(Borowiec)	-7.7	-8.3	-9.6	-10.4	-11.5	-12.5	-13.4	0.3	3.5	3.5	
APL	(Laurel)	-0.8	-0.1	-0.7	0.1	-1.1	-1.0	-0.4	0.3	19.8	19.8	
AUS	(Sydney)	-390.9	-385.1	-377.5	-369.0	-365.7	-352.9	-331.7	0.3	3.0	3.0	
BEV	(Wien)	-5.2	-15.5	-16.2	-16.6	-18.7	-10.2	-6.6	0.3	3.0	3.0	

Today we get:

Time uncertainty at best at 1-2 ns (many labs are at 5-10 ns, a few > 20 ns)

Relative frequency uncertainty at best 10^{-16}
(commercial clocks at 10^{-12})



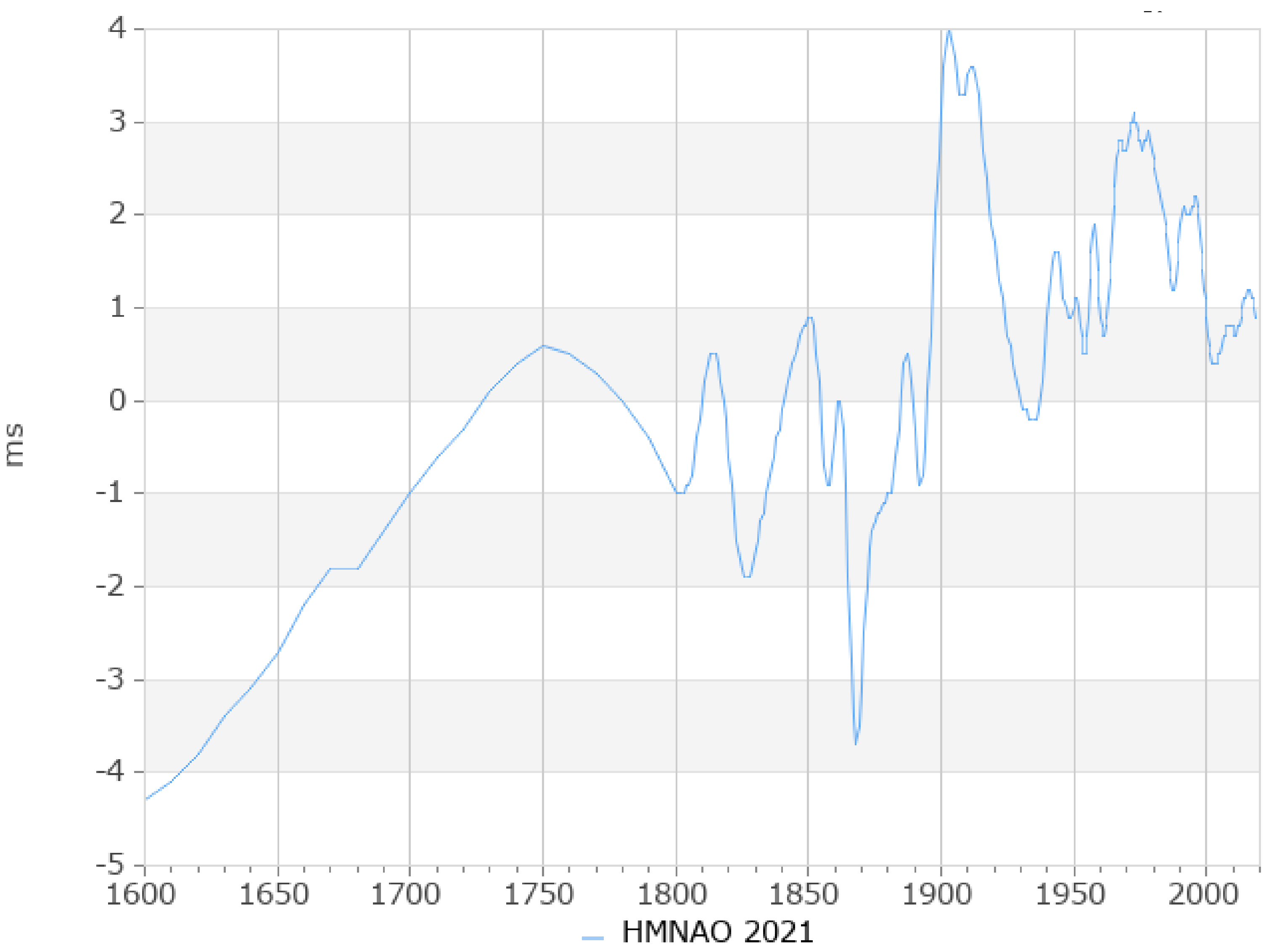
Coordinated Universal Time

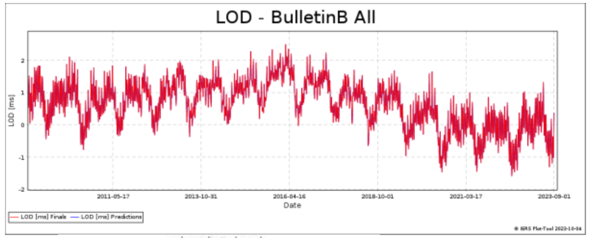
something is changing…

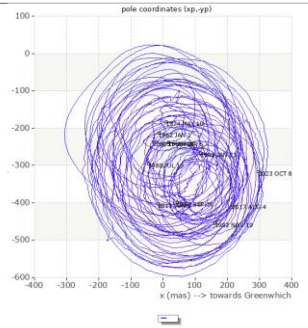
Secular slowing down

the Earth rotation rate is not constant, and not enough well known to be predictable

the leap second is decided with 6 month notice, when necessary



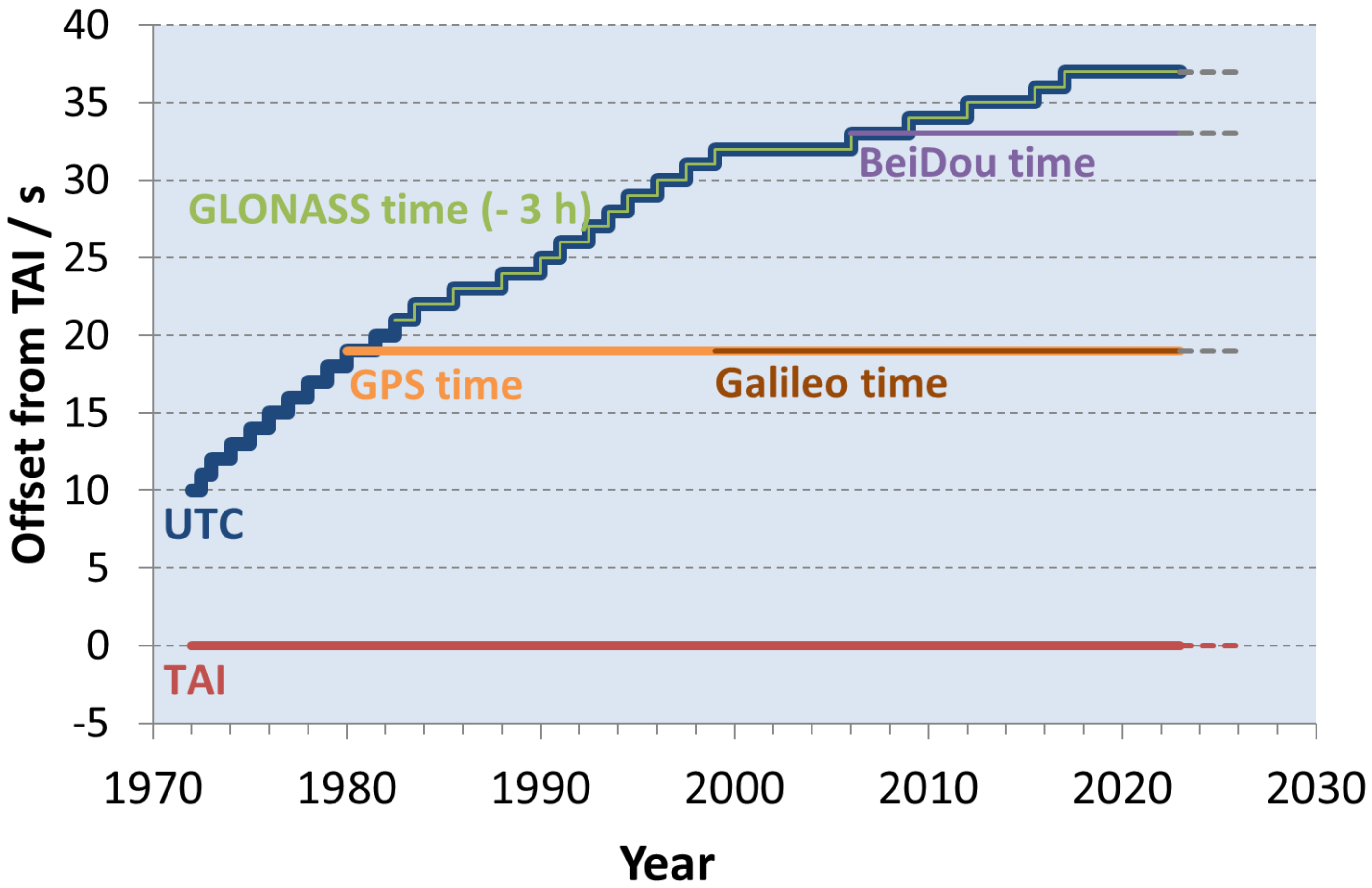




http://www.iers.org *International Earth Rotation and Reference Systems Service*

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

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

BUSINESS | CULTURE | GEAR | IDEAS | SCIENCE

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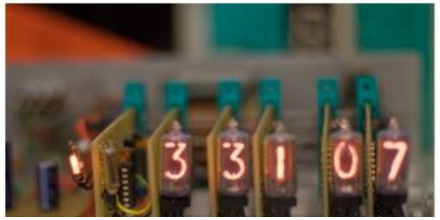
ROBERT MCMILLAN AND CADE METZ BUSINESS 07.02.12 07:54 PM

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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Politics | Investigations | Obits | Education | Science | Earth | Weather | Health | Royal | C

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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

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

NETWORKWORLD FROM IDG

'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

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

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

Consultative Committee on Time and Frequency User Survey (2021)

- > 200 answers
- The large majority asks to get rid of discontinuities in UTC
- GPS time and TAI are used, instead of UTC, as continuous time scales

Time travels on the network

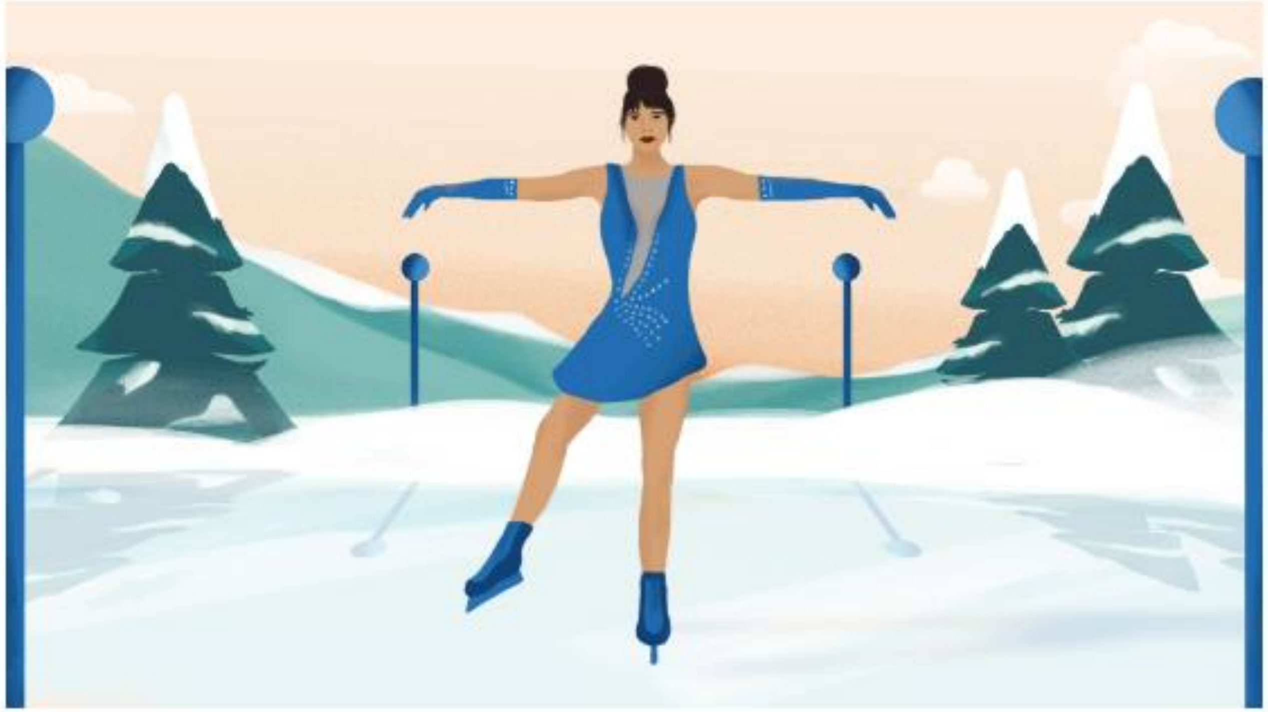
Computer operating systems are not easily able to handle a minute with 61 seconds

Engineering at Meta

Open Source Platforms Infrastructure Systems Physical Infrastructure Video Enginee

POSTED ON JULY 25, 2022 TO PRODUCTION ENGINEERING

It's time to leave the leap second in the past



By Oleg Obleukhov, Ahmad Byagowi

The leap second concept was first introduced in 1972 by the International Earth Rotation

https://engineering.fb.com/2022/07/25/production-engineering/its-time-to-leave-the-leap-second-in-the-past/

INTERNATIONAL UNION OF RADIO SCIENCE
UNION RADIO-SCIENTIFIQUE INTERNATIONALE
info@ursi.org www.ursi.org

XXXIVth General Assembly and Scientific Symposium
Rome 2021

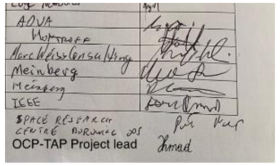
Council IV
Vote on URSI Resolutions

GASS 2021 : Vote on URSI Resolutions and Recommendation

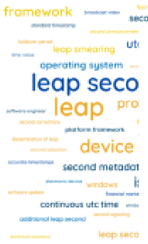
R1. Resolution on the need for a continuous reference time scale

The URSI Council,

Industry Perspectives & Insights on Impacts of Leap Seconds Practice in UTC Time Scale



Companies and trade association members from IT, Timing and Electric Power industries articulate their insights into impacts of leap seconds practice in UTC time scale on their products and services, as well as their customers. From this collective experience, a shared preference emerges for a continuous UTC time scale without additional leap seconds.



Contact information at
available from Dr. Patr

May 1, 2022

IGS INTERNATIONAL GNSS SERVICE

Statement on Leap Second

The International GNSS Service (IGS) publishes many GNSS analysis products based on satellite data collected from a network of over 400 ground stations. In keeping with the IGS's legacy conventions, data and product records have timestamps aligned to TAI – 19 seconds making its timescale consistent with GPS System Time, Galileo System Time and QZSS System Time. These timestamps vary, however, with respect to UTC depending on the present number of leap seconds.

Systems underpinning critical infrastructures, need a continuous timescale
Several “ah hoc” methods have been developed to avoid leap seconds

- Ignore leap seconds after an initial synchronization
  - GPS, Galileo, BeiDou system times.
  - Most current versions of Windows (till next synchronization)
- Stop clock for 2 seconds at 23:59:59 or 00:00:00
  - Network Time Protocol, Posix time on many computers
  - Two seconds have same name
  - Problems with causality, time ordering, time intervals
  - Leap second has no indicator
- Reduce frequency of clock over some interval
  - Google (24 h before), Microsoft, Facebook (18 h after), Alibaba (12 h before – 12 h after) …

All of these methods are not in agreement with UTC on the leap second day, and many disagree with each other

Users cannot tell which method is used by a time source, especially a posteriori

Leap second and the alternative methods threatens the resilience of the synchronization

The leap second process in UTC needs to be revised

Solution to progress towards a continuous UTC

Increase the tolerance between the Earth rotation and UTC: |UT1 - UTC| to a new limit

(e.g. 1 min reached after ≈1 century or 1 hour reached after ≈ 5000 years) or to an unlimited value (= the difference UT1 – UTC will be let growing with no limit).

→ **UTC remains linked to UT1**, the Earth's rotation angle, whose origin is the reference meridian of Greenwich.

In the daily life, there is no change for the general public since the evolution of |UT1 - UTC| will remain negligible compared to the +/- 15 min seasonal day variations, for centuries. The general perception of conformity to astronomical phenomena is not challenged.

Users needing the knowledge of UT1-UTC find accurate and real time estimations by the services of IERS, NASA, GNSS, ITU-R broadcast signals

In the '70s UTC was used as approximation to UT1 mostly for navigation with traditional optical instruments.

Approximation UTC ≈ UT1 corresponds to an uncertainty in the position up to 400 m (at the equator). It is used only in low accuracy applications (as amateurs telescope pointing).

But it is not adapted for high precision applications (as high accuracy astronomy and space applications) that are already using the IERS and NASA estimates with 10 microsecond uncertainty, corresponding to about 0.3 cm uncertainty in the position

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,

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

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

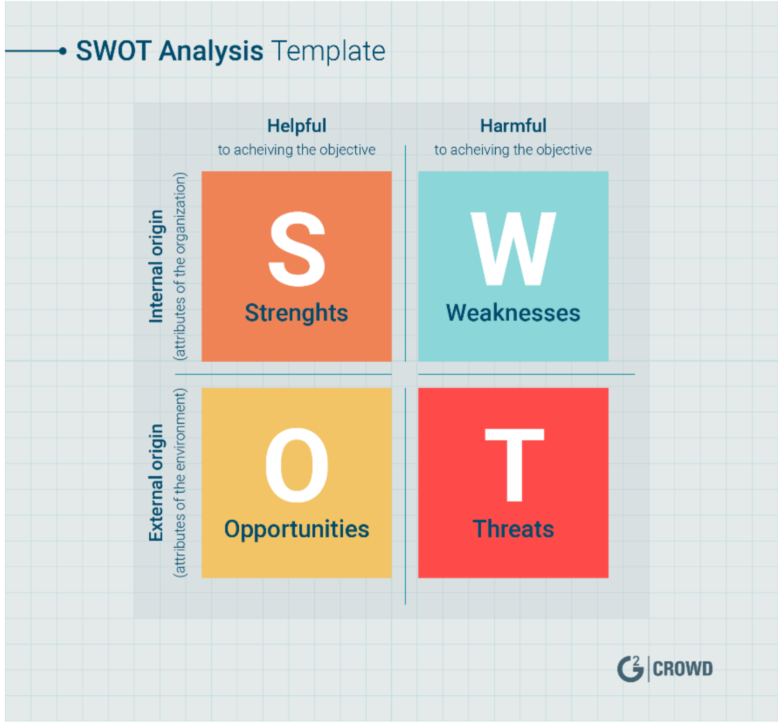
……………….

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

The CCTF Task Group has *to* ***prepare the draft resolution for the CGPM 2026*** *with the extended tolerance value of UT1-UTC, …*

Extended tolerance: 3 options

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



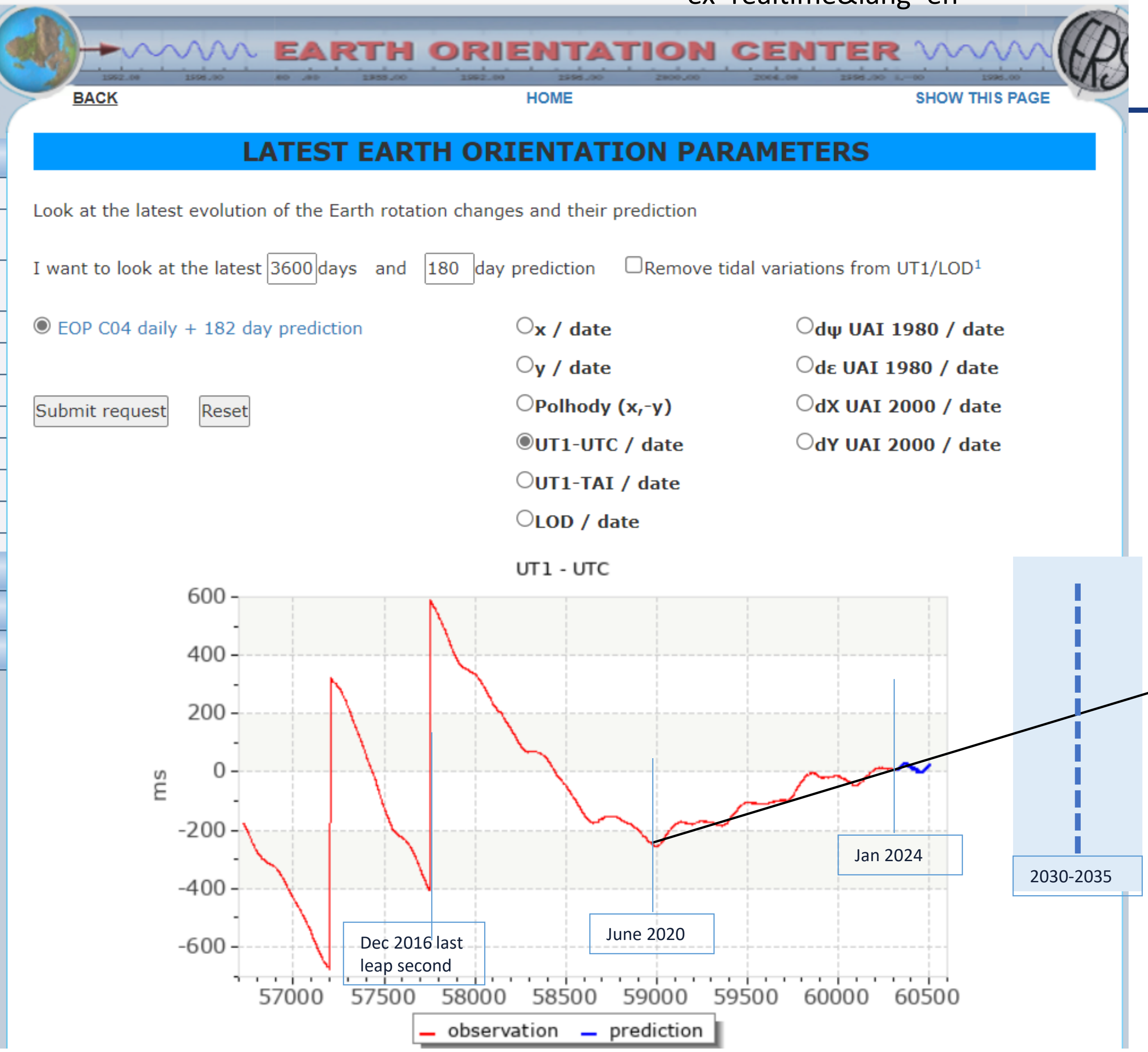
When?

- Some countries recommend 2035 to update technological systems, other countries and user communities are urging the change
- Ready for a negative leap second?

Work in progress

Is the Earth deciding for us?

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



≈200 ms/3 years

Reaching 600 ms in 10 years?

We receive requests from BIPM member states and stakeholders NOT to allow a negative leap second

Possibility for the first negative leap second ?

A negative leap second coming soon?

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

March 27 on Nature: UTC as now defined will require a negative discontinuity by 2029 (could have been in 2026)

https://www.nature.com/articles/d41586-024-00850-x

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.

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/

Stay tuned, in 2035 (or before?) we will change the procedure to keep UTC aligned with the Earth rotation

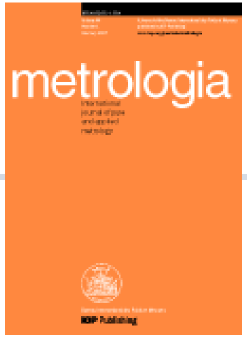
No reliable prediction is possible in the long term, let's observe the Earth rotation and let's the future generations decide

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

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

Metrologia special focus

https://iopscience.iop.org/collections/0026-1394_challenges-in-time-and-frequency-metrology



Review

OPEN ACCESS

Roadmap towards the redefinition of the second

N Dimarcq *et al* 2024 *Metrologia* **61** 012001

+ Open abstract View article PDF

Paper

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Achieving traceability to UTC through GNSS measurements

P Defraigne *et al* 2022 *Metrologia* **59** 064001

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Towards a consensus on a continuous coordinated universal time

Judah Levine *et al* 2023 *Metrologia* **60** 014001

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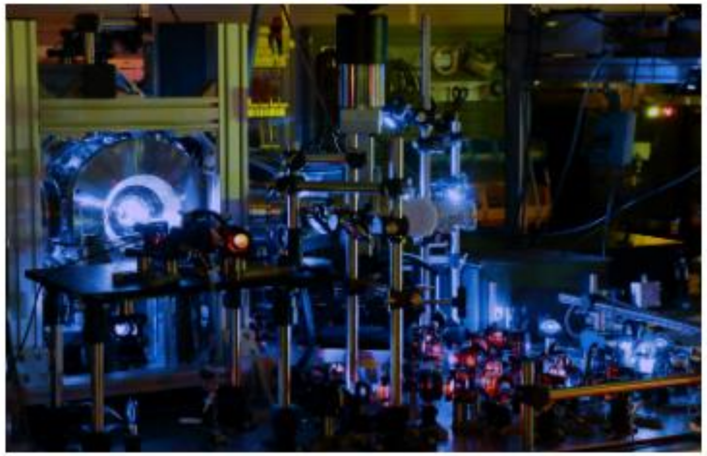
Focus on Challenges in Time and Frequency Metrolog



Thanks for your attention
Thanks to CCTF and its Working Groups for all contributions

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