



Task Force on the Roadmap for the redefinition of second

Introduction

Noël Dimarcq, CIPM, President of CCTF

Patrizia Tavella, Director of BIPM Time Department

Outline

- **Task Force on the Roadmap for the redefinition of second: Objectives and Composition**
- **Update of conditions and criteria to change the definition**
- **Conclusion, actions and schedule**

Discussion on the redefinition of the second at CCDS (1963)

R. Essen, "The birth of atomic time", Upfront Publishing, 2015



Topics discussed:

- Conditions for a change of the definition
- Choice of the atom (Cs, H) or molecule ?
- Radio techniques for comparisons

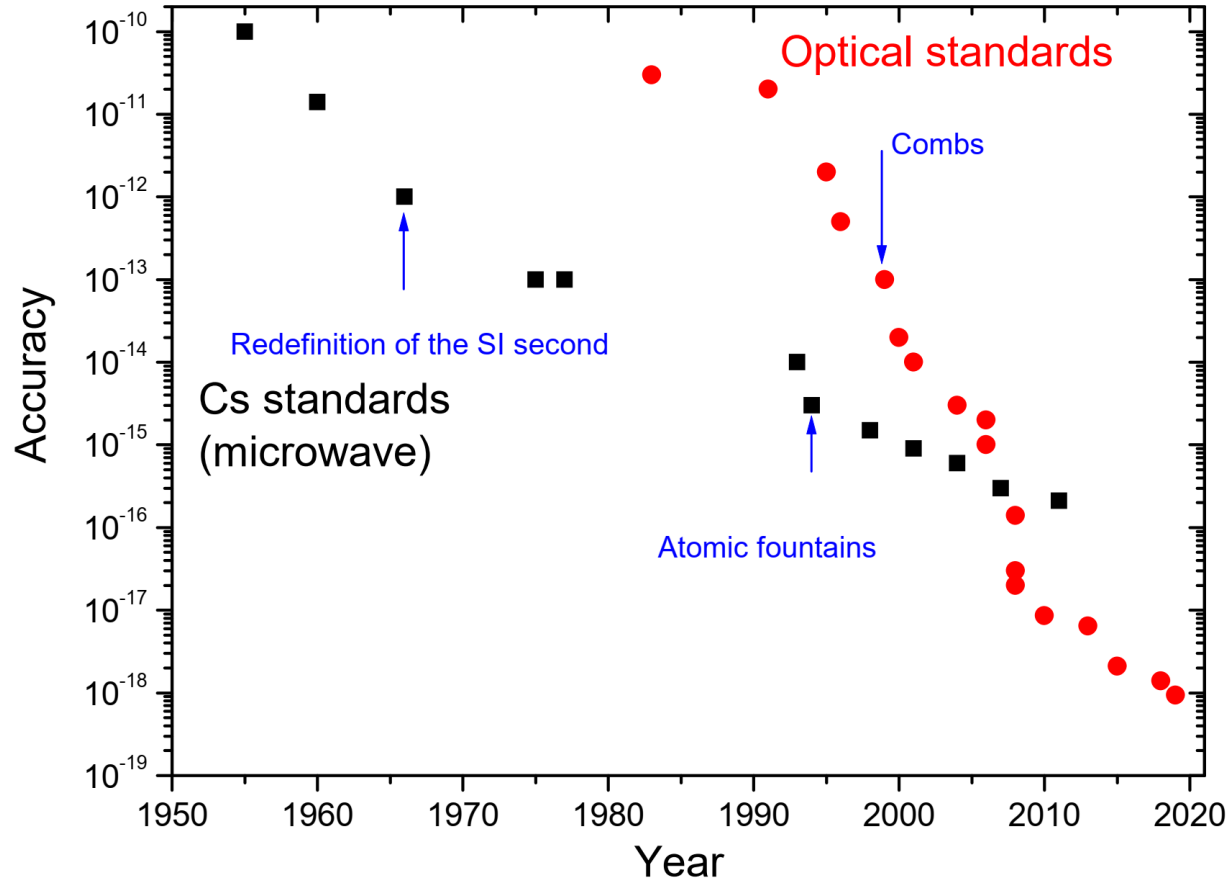
RECOMMANDATIONS

1) the SI second be defined as the duration of a specified number of periods of a specified transition between two energy levels of an atom or a molecule

2) the definition of the second (when it will be time to choose the transition) be in accordance with the value of 9 192 631 770 Hz attributed to the radiation corresponding to the transition between the two hyperfine levels of the unperturbed ground state of the ^{133}Cs atom.

To review the long process to measure the Cs frequency in terms of Ephemerids second see Metrologia 42 (2005) S10–S19 "The definition of the 'atomic' second" by S. Leschiutta

Roadmap towards the redefinition of the second



Long term work of CCTF and its WGs (WG on strategic planning)

Existing CCTF strategy document and roadmap (2016) by WG on strategic planning, including criteria for the redefinition of the second (available on CCTF webpage)

→ Update of the existing roadmap by setting up a dedicated CCTF Task Force on this topic

Objectives of the Task Force

Objectives:

- ◆ **Prepare an updated and detailed roadmap of redefinition of the second for the CGPM 2022, identifying the intermediate objectives and open issues, based on collect of information and critical assessment;**

- ◆ **On short term:**
 - Video presentations at CCTF Session 22-1 in Oct. 2020
 - Update of conditions and criteria to change the definition
 - Questions (to CCTF members, other NMIs, stakeholders, ...) concerning the redefinition of the second

- ◆ **On mid-term, preparation of:**
 - Presentations to CCTF Session 22-2 in March 2021 of the status of activities, taking into account the responses to the questions and the comments on the criteria. Proposal of different options for way forward and roadmap
 - White paper and contribution to CGPM if any (2021)
 - Article submitted to Metrologia from the white paper content (2022)

Composition of the Task Force

Chair: N. Dimarcq and P. Tavella

3 Subgroups gathering 40 worldwide contributors:

A - Request from user communities and NMIs (17 members, co-chairs:)

B - Atomic frequency standards, and possible redefinition approaches (12 members + 4 external experts, co-chairs:)

C - TF Dissemination and time scales (13 members + 1 external expert, co-chairs:)

Work of the task force in interaction with WG on strategic planning (subgroups co-chaired by members of CCTF WG SP and experts from NMIs)

Meetings: Kick-off on June 24 + meetings on Aug. 26 and Sept. 24

Intensive and important work done: definition of ToR, preparation of video presentations and questions, update of the criteria, ...

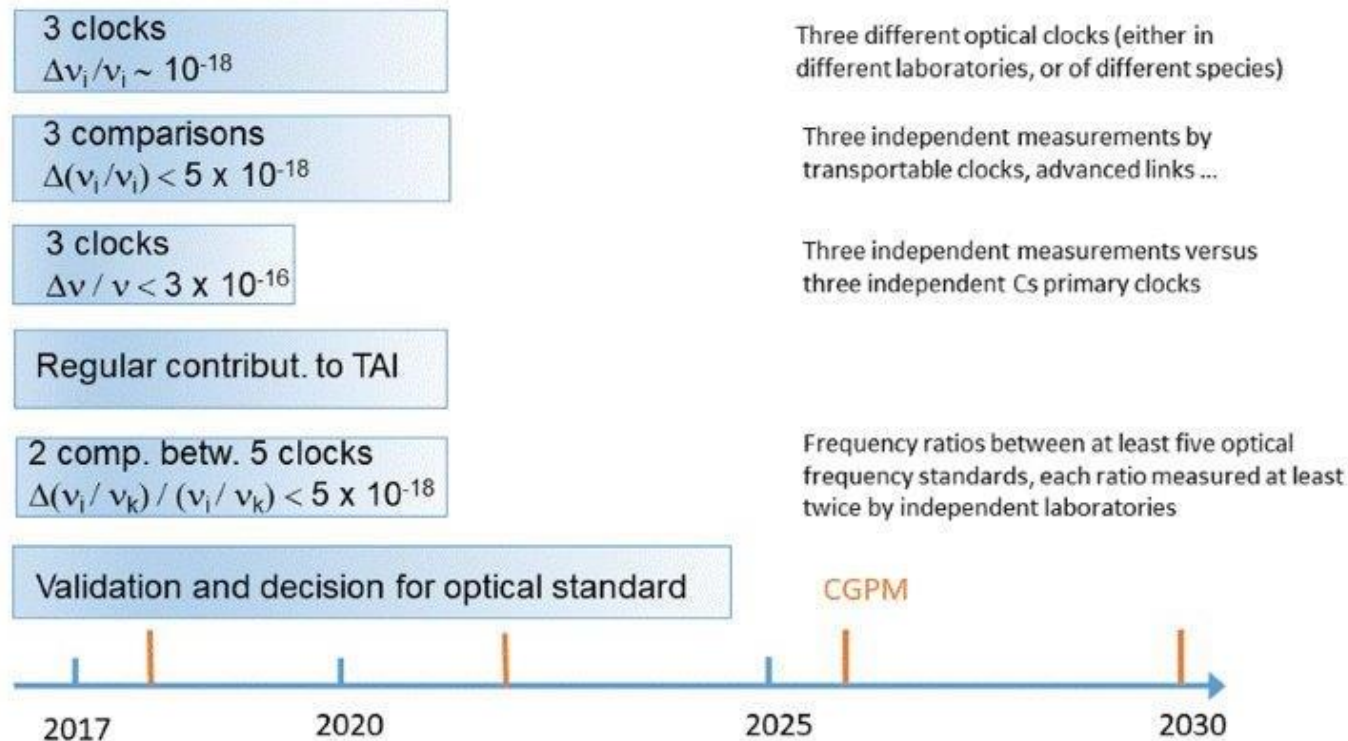
→ Thanks to all contributors for all the work and BIPM time departement for the efficient support

Goals for a new definition

- **Offer an improvement** by 10/100 on short term after the redefinition (reaching 10^{-17} / 10^{-18} relative frequency accuracy) and a much 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/UTC, with a significant improvement of its frequency accuracy (*risk of degradation of the quality of TAI if there is not enough high quality data of the new optical primary frequency standards*)
- **Enable the dissemination of the unit** towards wide categories of users
- **Be acceptable** by all NMIs and stakeholders
- **Essential to see a significant improvement of the quality of the realization of the definition and of time scales (TAI/UTC) as soon as the definition is changed.**

Criteria fixed in 2016 for a change of the definition

Roadmap towards a redefinition of the SI second (CCTF 2016)



These criteria are marked with ★ in the next slides

<https://www.bipm.org/utis/en/pdf/CCTF-strategy-document.pdf>

1) Conditions to change definition: Frequency standards and TAI

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

I.1) At least three 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, comparable 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 three 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 regularly contributions of optical clocks to TAI (as secondary representations of the second)

I.4) More than 3 state-of-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 not degradation of TAI with new PFS (+ Cs fountains as SFS) ★

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)

Regularly contributions of optical clocks to UTC(k)

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

Required

These must be achieved

Desirable

These can still be in progress

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 basis

II.2) At least three independent measurements of all optical clocks of (I.1) were compared in 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 $< 10^{-17}$

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 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

Required

These must be achieved

Desirable

These can be still in progress

3) Acceptance criteria of the new definition

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

III.1) Potential ultimate level of accuracy achievable on frequency standards, in time scale 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 realizations of the new definition (reliable operation, regular contribution to TAI, ...)
- maintain the operation of 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 have not optical clocks to realize the new definition. Autonomy of each country

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

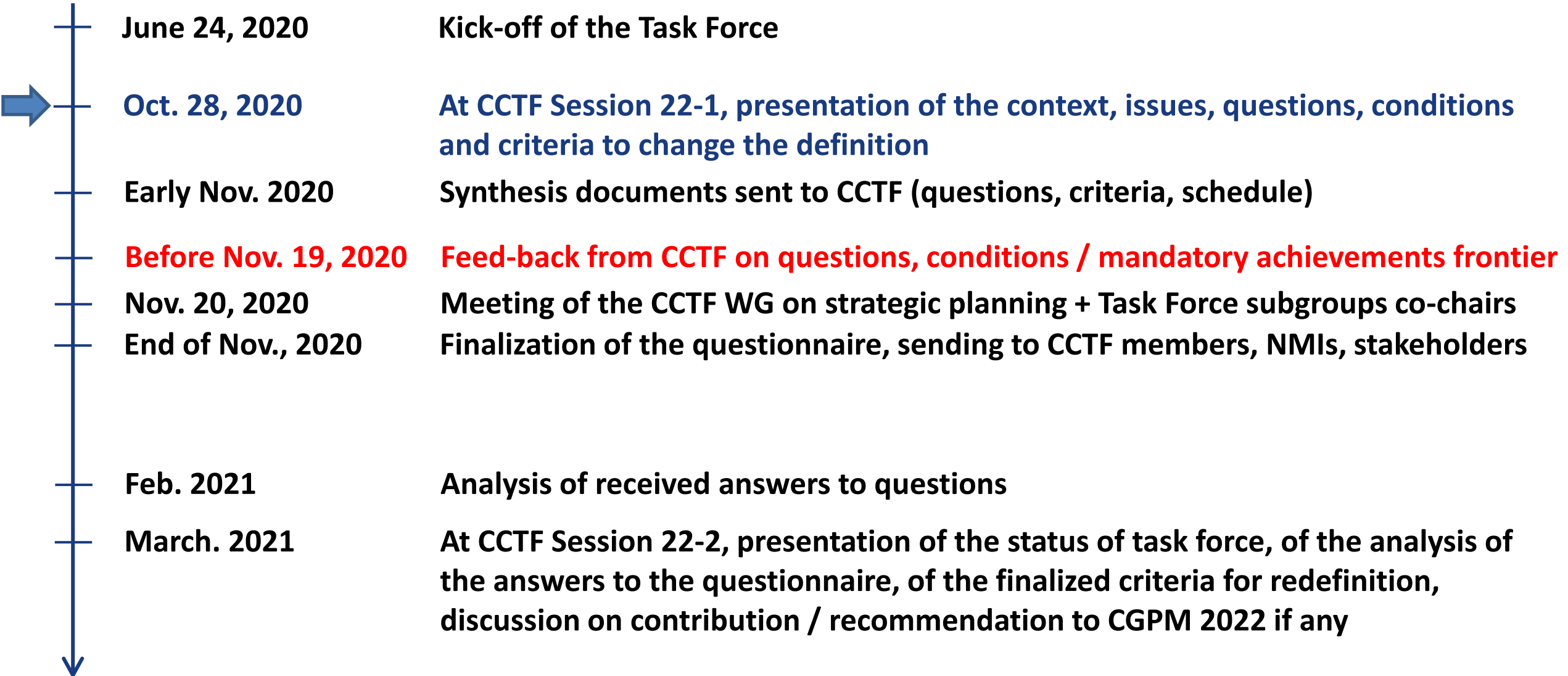
Required

These must be achieved

Desirable

These can be still in progress

Conclusion, actions and schedule (short term)





Thank you for your attention

CONSULTATIVE COMMITTEE
FOR TIME AND FREQUENCY