The Clocks Do Not Agree

The redefinition of the second is reported as a story of convergence. This brief asks whether that is what the primary documents record.

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What this brief examines

This brief examines the roadmap that sets the criteria for redefinition, the CIPM's own published frequency values and the adjustments behind them, the international comparison campaigns of 2022 to 2026, and the strategy documents of the Consultative Committee for Time and Frequency. It reads what those documents record against the published account of the same work, and includes the community's own case that the timetable holds.

The second is expected to be redefined around 2030 on an optical transition, replacing the caesium standard adopted in 1967. Public accounts describe this as a story of convergence: better clocks, closing in on a better second. The documents are the test of that description.

What the redefinition requires

The roadmap document — Dimarcq et al., *Metrologia* **61** 012001 (2024) — establishes **eight mandatory criteria** that must be met before the definition changes, and six ancillary conditions that need not be fully met but bear on the quality of the result.

The mandatory eight concern: accuracy budgets of optical frequency standards; validation of those budgets through frequency ratio measurements; continuity with the caesium definition; regular contributions to International Atomic Time; sustainable comparison techniques; knowledge of the local geopotential; a definition permitting more accurate future realizations; and practical access to that realization.

The roadmap scores each criterion's fulfilment as of 2022. Two scores matter:

Criterion	Fulfilment
I.3 — Continuity with caesium	90–100%
III.1 — Allows more accurate future realizations	100%
II.2 — Local geopotential	70–90%
I.1 — Accuracy budgets	30–50%
I.4 — Contributions to TAI	30–50%
I.2 — Validation via frequency ratios	**<30%**
III.2.a — Documented realization procedure	**0%**

Criterion I.2 is the lowest-scoring of all, and it is the one everything else rests on. It asks for at least three measurements of unit ratios between standards on the same transition at *different* institutes, agreeing to within about 5 parts in 10^{18}, plus at least five non-unit ratios each measured twice by independent institutes to the same tolerance.

The roadmap's own assessment of what has actually been achieved against it is unusually candid:

> Strictly speaking the reported measurements of unit ratios are not between different institutes and should not count in this fulfilment level. Nevertheless, a fulfilment level at 0-20 % has been assigned based on these in house comparisons with uncertainties significantly lower than 5×10^{-18} that can be considered as the first step in the right direction.

And on the non-unit ratios:

> Again, this measurement alone is not valid in terms of the criterion which demands ratio measurements « twice by independent » institutes.

A criterion scored at under 30% is scored there on measurements the authors state do not properly count.

What the clocks actually show

The Bureau's own statement

The CIPM list of recommended standard frequency values was re-adjusted in 2025, approved by the CCTF in September 2025, and becomes active on 27 March 2026. Each species has its own published document. The following passage appears **verbatim and identically in eleven of them** — indium, ytterbium, both ytterbium-ion transitions, both mercury standards, calcium, all three strontium entries, and the rubidium-87 microwave standard:

> The 2025 analysis took into account 146 measurements, including 56 frequency ratios and 90 absolute frequency measurements (i.e. ratios to the ^{133}Cs frequency). […] A total of 1168 correlations between these input measurements were estimated and

considered in the adjustment. […]

> **An initial adjustment indicated that there were inconsistencies in the global body of published data. In the final adjustment, a random effect uncertainty equal to 5.3×10^{-17} was added in quadrature to all fractional uncertainties of input ratios so as to recover a Birge ratio of 1.**

A Birge ratio greater than one means the measurements scatter more widely than their stated error bars permit. Recovering a ratio of one means inflating every input uncertainty until they no longer disagree.

The documents add a second layer:

> The recommended standard uncertainty is **2.35 times** the square root of the corresponding diagonal entry in the covariance matrix of the adjustment. This multiplication factor was recommended by the CCL-CCTF WGFS to allow for as-yet-unidentified sources of uncertainty or correlation.

Set the inflation floor against the target. Criterion I.2 requires agreement at roughly **5×10^{-18}**. The consistency patch applied to make the global dataset cohere is **5.3×10^{-17}** — about ten times coarser than the threshold the redefinition demands.

Fourteen sigma

In December 2025 the BACON collaboration — NIST and JILA, operating aluminium-ion, ytterbium and strontium clocks — posted, and in July 2026 revised, a re-measurement of the frequency ratios it had first reported in *Nature* in 2021, this time with total fractional uncertainties at or below 3.2×10^{-18}.

From the abstract:

> Discrepancies in ^{87}Sr ratios at approximately 1×10^{-16} and the Al^+/Yb ratio at 1.6×10^{-17} in fractional units compared to our previous measurements underscore the importance of repeated, high-precision comparisons by different laboratories.

From the body:

> **The disagreement in the ^{87}Sr ratios is 14σ**, indicating a revision of the ^{87}Sr frequency by approximately 1×10^{-16}.

Three features of this deserve emphasis.

First, it is the same collaboration measuring the same quantity with better equipment, so the usual explanations — different methods, different laboratories, different conventions — do not apply.

Second, correcting for improved atomic coefficients makes the disagreement **worse**, not better: the authors state the deviations would move "from (14.5, 2.4, 13.9) to (15.4, 2.6, 14.7) in units of σ."

Third, they eliminated the obvious culprit. An end-to-end network loopback test measured an offset of $0.9(1.6) \times 10^{-19}$, confirming accurate operation of the instruments common to the affected ratios. The fibre link and frequency combs are not the explanation, and the discrepancy stands unexplained.

The authors' own framing of the wider record is worth quoting, because it is more damaging than the headline number:

> we note that historical frequency ratio measurements […] exhibit disagreement at the few $\times 10^{-16}$ level, albeit with significance at the 2-4 σ level rather than 14. […] With a larger data set, sophisticated meta-analysis methods can be employed to build consensus among measurements **overscattered relative to their individual uncertainties**.

That is a proposal to apply meta-analysis to data the field acknowledges scatter more than their error bars allow.

Independently, in Europe

This is not a single-laboratory anomaly. Two European campaigns found the same family of disagreements.

The ROCIT campaign (ten clocks, six countries, 38 frequency ratios, March 2022; Lindvall et al., *Optica*) reported: an unexplained 4×10^{-16} instrumental offset at INRIM whose "origin […] has not been identified"; a **$1.46(21) \times 10^{-16}$** difference between the PTB and SYRTE strontium clocks — two clocks on the same transition, whose ratio should be exactly one — indicating "an uncontrolled frequency shift at the 10^{-16} level"; and mutually inconsistent local measurements from which, in the authors' words, "it is impossible to conclude unambiguously from the measurements in this campaign alone whether the offset is with the PTB Sr clock or with the reference values."

A second campaign (seven clocks, four national institutes, early 2023; Pizzocaro et al., *Physical Review Research*) found a 4σ disagreement in the ytterbium-to-strontium ratio against the earlier BACON measurement, and concluded:

> Some frequency ratios measured in this campaign show inconsistencies with previous measurements, in particular among some ^{171}Yb/^{87}Sr ratios, as also observed in a recent campaign conducted in the USA. **However, no experimental issue or overlooked systematic effect has so far been reported for any of these measurements.**
>
> **Resolving these inconsistencies is a challenge towards the redefinition of the second and it will require further effort from the metrology community worldwide.**

Three campaigns on two continents, plus the Bureau's own adjustment, independently reporting the same unresolved disagreements.

A published standard value that was wrong

The clearest single illustration is checkable with a calculator.

The ROCIT campaign found that every measured ratio involving strontium-88-ion was offset from the recommended value by a little over

2×10^{-15}, and concluded that the published CIPM value "is offset from the unperturbed transition frequency by approximately twice its assigned uncertainty," the earlier determination being "in the light of recent results [...] to be considered suspect."

The 2025 adjustment moved it:

	Recommended frequency (Hz)	Relative uncertainty
2021	444 779 044 095 **486.3**	1.3×10^{-15}
2025	444 779 044 095 **485.347**	1.7×10^{-16}

The shift is −0.953 Hz, or -2.14×10^{-15} fractional — **1.65 times the 2021 value's own stated standard uncertainty**, and 12.6 times the new one.

An international recommended value for a secondary representation of the second was wrong by more than its stated error bar, was flagged by a measurement campaign in 2022, and was corrected in 2025.

(Arithmetic note for anyone rechecking: these figures exceed double precision. Computed in floating point the shift appears as −0.9375 Hz. Use exact decimal arithmetic.)

No agreement on what the second should be

Beneath the measurement problem sits a prior one. The CCTF Strategy 2025–2035 records:

> In 2025, there was no clear consensus neither on the choice between Option 1 (one species) and Option 2 (ensemble of species) for the new definition, nor on the choice of the preferred species or ensemble of species... Moreover, the maturity of the optical frequency standards is growing impressively even if noticeable inconsistencies in some comparisons of OFS and in a part of the frequency ratio measurements with OFS have been observed at recent comparison campaigns.

This is the upstream source of the "noticeable inconsistencies" language that reaches the 28th CGPM in Draft Resolution B. The Conference text is not diplomatic hedging; it is a faithful summary of a documented technical state.

The three options. Option 1 fixes the frequency of a single transition, as caesium does today. Option 2 fixes a weighted geometric mean of several transitions — in variant 2a with fixed weights, in 2b with weights the CIPM may revise over time. Option 3 would fix an additional fundamental constant, most naturally the electron mass.

Option 3 is ruled out on numbers, in the roadmap's own words: the electron mass is known to 3.0 parts in 10^{10} and the Rydberg constant to 1.9 parts in 10^{12}, "several orders of magnitude larger than the present realizations of the unit of time [...] Consequently, Option 3 is not practical in the current state of science and technology." That rejection is explicitly contingent on present technology, not fundamental.

Why no species has won. The roadmap explains the deadlock directly:

> Interestingly, it seems there is not a fundamental limitation for the accuracy of the optical clocks that are being developed based on different ion and neutral atom species. **Most of the currently proposed optical transitions can potentially achieve an uncertainty level below 10^{-18}.**

There is no natural winner. Aluminium-ion holds the accuracy record at 9.4×10^{-19}, followed by ytterbium lattice (1.4×10^{-18}), strontium lattice (2.0×10^{-18}) and the ytterbium-ion octupole transition (2.7×10^{-18}). Ions win on accuracy; lattice clocks win on stability, reaching instabilities near 5×10^{-17} at one second against roughly 1×10^{-15} for single ions. That trade-off is the real axis of the dispute.

Two further details are telling. The 2025 adjustment **added** two species — indium-115 and lutetium-176 — so the candidate field is still widening, not narrowing, five years before the decision. And lutetium rests on one laboratory's measurement: "With this value, determined by a single laboratory, the CCTF considered it prudent to attribute a standard uncertainty increased by a factor of three."

The roadmap also records, under ancillary condition III.4: **"No available commercial OFS."**

The case for optimism, stated fully

The community's own confidence is genuine and should not be discounted.

The CCTF believes the timeline holds. From the same strategy document that records the consensus failure: "Criticalities are identified and a clear mitigation plan is being developed [...] Thus, all the criteria could be realistically fulfilled by 2030."

2030 is a decision point, not a deadline. The strategy is explicit: the 29th CGPM is "a decisive milestone, either to approve the new definition or to postpone it to the 30th CGPM in 2034." The slip path is designed in. A brief presenting 2030 as a promise about to be broken would be misreading the documents.

The weakest criterion is being attacked directly. The European fiber-network campaign, published in 2026 from measurements taken in early 2023, reported that the ytterbium-ion octupole clocks at NPL and PTB "demonstrated agreement within an uncertainty of 7.7×10^{-18}, marking the first international verification of two independently developed optical clocks below one part in 10^{17}." That is precisely what criterion I.2 asks for. It is not yet at the 5×10^{-18} target, but it is within a factor of 1.5, and nothing like it existed when the criterion was scored below 30% in 2022.

BACON claims the milestone outright: “With total fractional uncertainties at or below 3.2×10^{-18}, these measurements meet an important milestone criterion for redefinition of the second.”

The inconsistencies are being found because the machinery works. *Physics World*, reporting the campaign, put the fairest possible argument: “the benefit of comparing so many clocks at once and using more than one link technique is that it was often possible to identify the source of problems.” Lindvall et al. draw the same lesson from the unexplained problem at INRIM: “This serves to illustrate the importance of carrying out large, coordinated measurement campaigns with multiple clocks and links running simultaneously in order to identify and eliminate such inconsistencies.” Disagreements surfacing now is what successful verification looks like. They were presumably always there; previously nobody could see them.

And the trend is right. Optical standards contributing to International Atomic Time rose from one in October 2025 to five by September 2026. The 2025 adjustment cut the strontium-ion uncertainty roughly eightfold and calcium-ion threefold.

What the coverage has and has not said

One correction to a claim that might be assumed and would be wrong: **the inconsistencies have been reported.** *Physics World*, on 2 July 2025, wrote that “the results did not always confirm the expected values and there were some inconsistencies in the measurements,” and noted that “before the redefinition, even lower uncertainties will be required.” That is accurate, sourced reporting of exactly this subject.

What no general-audience account appears to have reported:

- any **quantification** of a disagreement — not the 14σ, not the 1.46×10^{-16} between two strontium clocks, not the 4×10^{-16} instrumental offset;
- the **consensus failure** on single species versus ensemble, or on which species;
- that a **published CIPM recommended value** was wrong by 1.65 times its own stated uncertainty and was silently corrected;
- the Bureau’s own statement that the **global dataset is internally inconsistent**, and the 5.3×10^{-17} patch applied to it;
- the **2034 postponement path** written into the strategy.

The sharpest illustration: a *Nature* research highlight published on 4 September 2026 — three days after the European campaign paper whose own conclusion states that “no experimental issue or overlooked systematic effect has so far been reported for any of these measurements” — was headlined **“Super-precise optical clocks in four nations tick in harmony”** and reported only the agreement.

Conclusion

The honest reading is not that the redefinition is failing. It is that the second is being redefined through a process that has begun, for the first time, to measure its own reliability — and is finding that the published uncertainties were optimistic. That discovery is a success of the verification program, and the community says so plainly in documents anyone can read.

But it is also true that the world’s best clocks disagree by fourteen standard deviations on a quantity they have both measured twice; that the Bureau responsible for the definition has inflated every input uncertainty by a floor ten times coarser than the redefinition threshold in order to make its own dataset cohere; and that with four years to a scheduled decision there is no agreement on what the new second should be made of.

Those three facts belong in any account of where the second is going. So far they have been in the primary documents and almost nowhere else.

Sources

Roadmap and criteria - N Dimarcq et al., “Roadmap towards the redefinition of the second,” *Metrologia* **61** 012001 (2024), DOI 10.1088/1681-7575/ad17d2 — https://iopscience.iop.org/article/10.1088/1681-7575/ad17d2 (preprint: https://arxiv.org/abs/2307.14141). Criteria and fulfilment levels are Table 4. - BIPM, frequently asked questions on the redefinition of the second — https://www.bipm.org/en/faq-redefinition-second

The CIPM recommended values and the inconsistency statement - BIPM, recommended values of standard frequencies (2025 adjustment, CCTF Recommendation 24-2, active 27 March 2026) — https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies - CCTF 24th meeting (session II), 2025 — https://www.bipm.org/en/committees/cc/cctf/24-_2-2025 - Supplementary data and covariance matrix — https://www.doi.org/10.59161/StdFreq2026 - H S Margolis et al., “The CIPM list ‘Recommended values of standard frequencies’: 2021 update,” *Metrologia* **61** 035005 (2024) — https://iopscience.iop.org/article/10.1088/1681-7575/ad3afc

Measurement campaigns - A Aeppli, … J Ye et al. (BACON), “Atomic clock frequency ratios with fractional uncertainty $\leq 3.2 \times 10^{-18}$,” arXiv:2512.21428 — https://arxiv.org/abs/2512.21428 - T Lindvall, … H S Margolis et al., “Coordinated international comparisons between optical clocks connected via fiber and satellite links,” *Optica* 12(6), 843 (2025), DOI 10.1364/OPTICA.561754 — preprint https://arxiv.org/abs/2505.06763. **The inconsistencies are in sections 5 and 7 of the body; the abstract reports only the positive result.** - M Pizzocaro, … H S Margolis et al., “International Optical Clock Comparison Using the European Optical Fiber Network,” *Phys. Rev. Research*, DOI 10.1103/l4bh-ryxs — preprint https://arxiv.org/abs/2604.27963

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2afe-d15c-0909-1f03406bbb8f - Draft Resolutions of the 28th CGPM, Version 5 (13 July 2026); Draft Resolution B at page 21 — https://www.bipm.org/documents/20126/284836054/CGPM-2026-Draft-Resolutions.pdf - BIPM *Circular T* (optical standards contributing to TAI appear in Section 3, Table 1) — https://webtai.bipm.org/ftp/pub/tai/Circular-T/cirt/

Coverage referenced - M Boerkamp, “New definition of second ticks closer after international optical-clock comparison,” *Physics World*, 2 July 2025 — https://physicsworld.com/a/new-definition-of-second-ticks-closer-after-international-optical-clock-comparison/ - “Super-precise optical clocks in four nations tick in harmony,” *Nature* research highlight, 4 September 2026 — https://www.nature.com/articles/d41586-026-02741-9

Note on verification. Quotations above were read from the primary documents, except where a passage is attributed to coverage. Three items were not independently confirmed and are excluded from the body: the enumeration of the four possibilities the CCTF Task Force shortlisted in 2025 (the strategy states a shortlist exists but does not list its contents); whether aluminium-27 was included in the 2025 adjustment, since no standalone 2025 document for it appears; and the contents of the *Science* magazine feature on the redefinition, which could not be retrieved. Anyone extending this brief should check the last of these before repeating the coverage assessment.

This brief

Version 1.1, corrected 26 September 2026. First published 20 September 2026 as Version 1.0. When this brief is corrected, the version number is incremented, a dated note is added here, and the change is listed at sothic.org/corrections. Nothing is amended silently.

Correction note, 26 September 2026. Version 1.1 makes these corrections:

- A passage attributed to Lindvall et al. joined words from *Physics World*’s coverage to words from the paper. The two are now quoted separately and each is attributed to its source; the paper’s sentence is quoted in full.
- The roadmap’s assessment was quoted with its sentence cut short without an ellipsis. It is now quoted in full.
- Two sentences omitted from the BIPM standard-frequency passage are now marked with an ellipsis.
- The passage appears in eleven of the per-species documents, not ten; the rubidium-87 microwave standard is added.
- The BACON re-measurement was first posted in December 2025 and revised in July 2026; the brief had dated it July 2026 only.
- The European fiber-network campaign is now described as published in 2026 from measurements taken in early 2023.
- The *Nature* research highlight appeared three days after the campaign paper, not two.
- The *Optica* citation for Lindvall et al. now gives volume 12, issue 6, page 843 (2025).

Zenodo Version 1.0.1 (24 September 2026) replaced only the PDF’s document properties; its text is identical to Version 1.0.

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