Time metrology at the BIPM

Towards a new definition of the SI second

The SI second – current situation

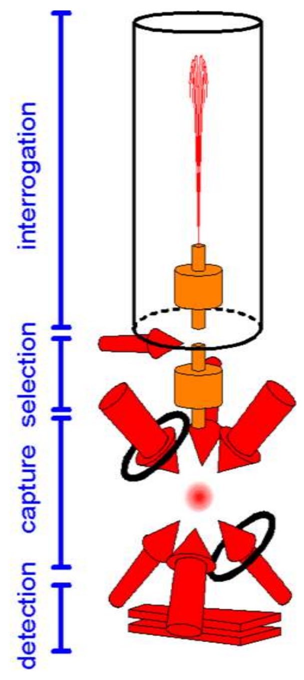
13th meeting of the CGPM (1967)

Resolution 1

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.

Resolution 2

Considering that the caesium frequency standard is still perfectible and **current experiments allow the hope of producing other standards with even better qualities to define the second**, invites …. laboratories in the field of atomic frequency standards to actively pursue their studies.



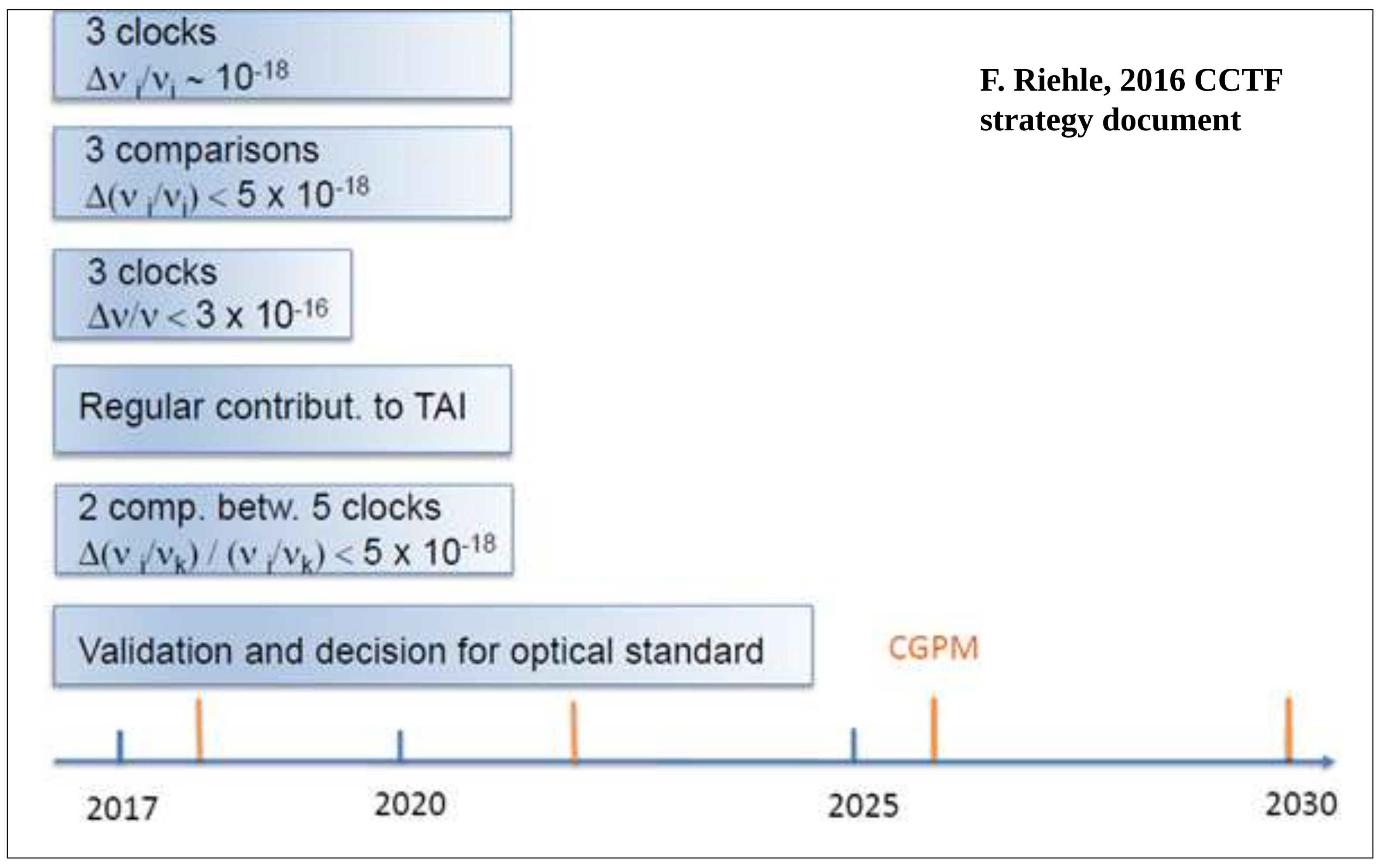
1st generation: Thermal atomic beams

- Used to calibrate TAI since its origin

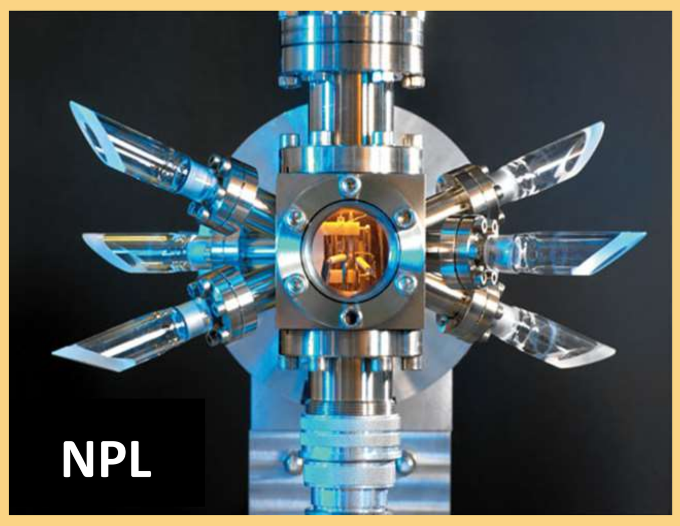
2nd generation: Laser-cooled atomic fountain

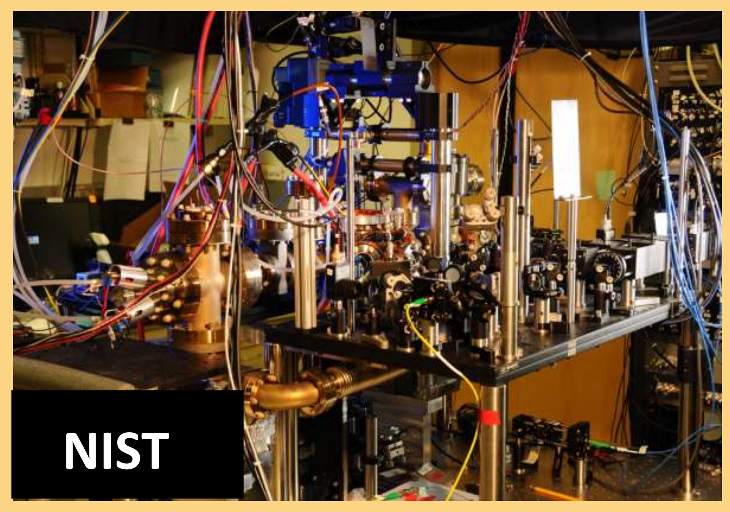
- Uncertainty budget now close to 1×10^{-16} and reaching its limits

Roadmap towards a redefinition



Performance of optical clocks





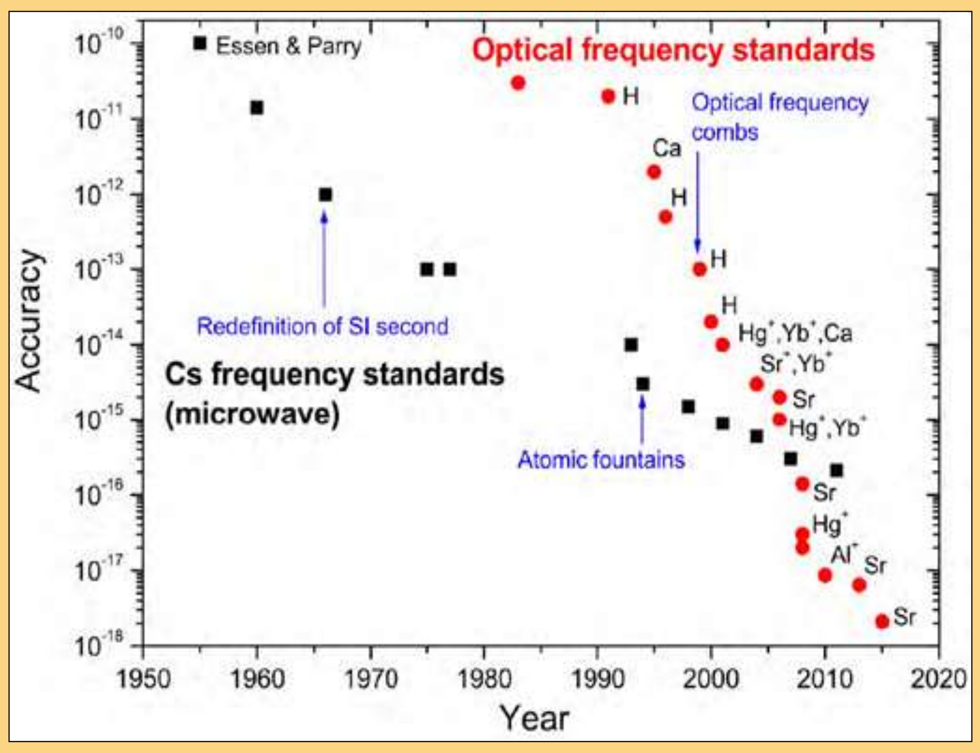
Progress in the construction of optical clocks represents a potential approach to 10^{-18} accuracy in a few years, and opens the way to a **redefinition of the second**.

Two main types of optical frequency standards

- (Single) ion in an EM trap
  - Low SNR
  - Many ions studied
- (Many) neutral atoms trapped in a lattice
  - High SNR
  - Reduce shifts / interactions between atoms

Optical clocks now outperform Cs frequency standards

- Best systematic uncertainty budget
  - Lattice: $\sim 2 \times 10^{-18}$
  - Ion trap: $\sim 3 \times 10^{-18}$



Secondary representations of the second in 2018

Role of the CCL-CCTF Working Group on Frequency Standards (WGFS)

- to maintain, together with the BIPM, the list of recommended frequency standard values and wavelength values for applications including the practical realization of the definition of the metre and secondary representations of the second

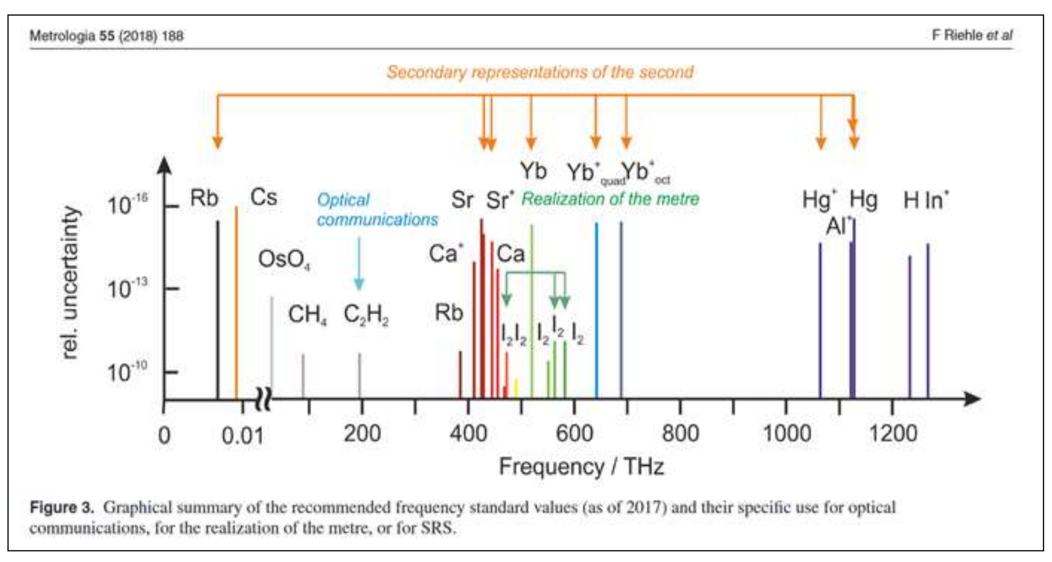
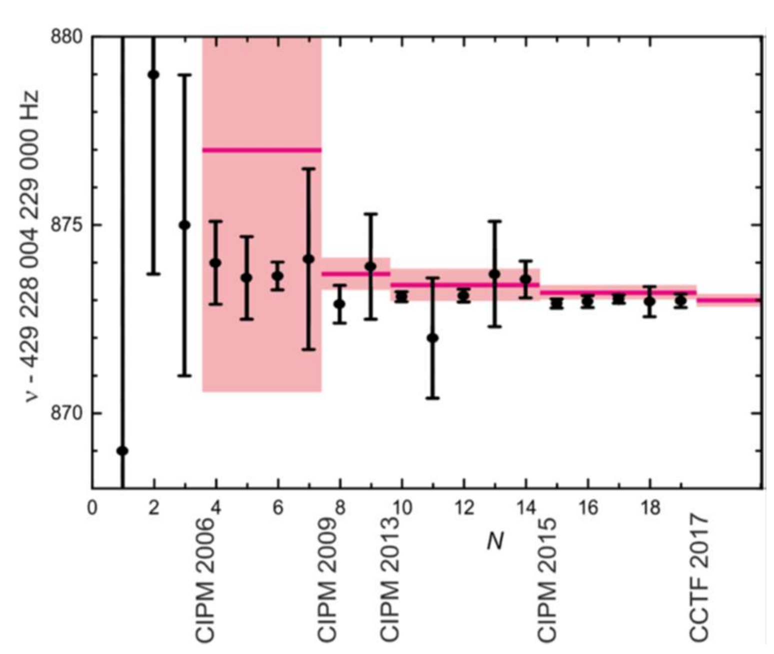


Figure 3. Graphical summary of the recommended frequency standard values (as of 2017) and their specific use for optical communications, for the realization of the metre, or for SRS.

- Example of the ^{87}Sr transition
  - Value and uncertainty revised five times since 2006
  - Conventional uncertainty now at 4×10^{-16} limited by Cs uncertainty.



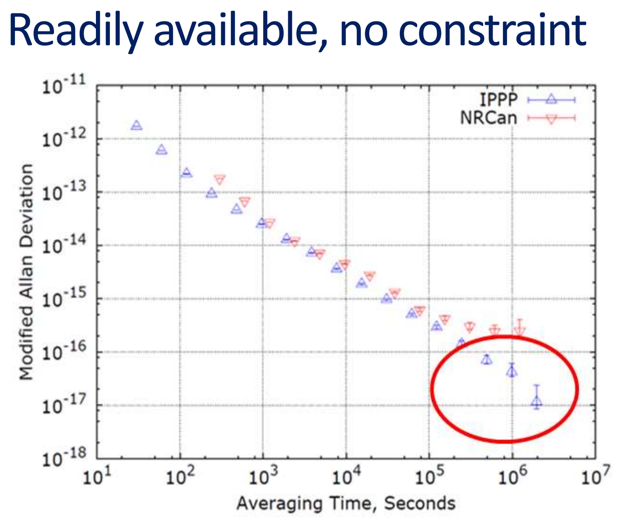
How to compare optical clocks at a distance?

- At the 10^{-18} accuracy level
  - Only fibre links can make it within hours
  - Presently limited to (sub)continental links
  - Earth-space optical links in the future
- At the 10^{-17} accuracy level
  - Several techniques can provide such performance

GPS IPPP

$< 1 \times 10^{-16}$ after several days

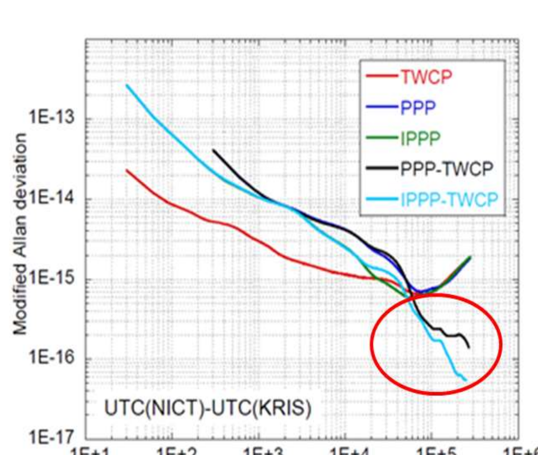
Readily available, no constraint



Two way CP

$< 1 \times 10^{-16}$ after 1 day?

Available, with constraints



ACES MWL

1×10^{-17} after 1/several days?

To be launched > 2020

- To compare two clocks at a distance, one has to account for their relativistic frequency shift
- Conversely one can directly measure the geopotential (height) difference between any two clocks (1 cm $\approx 1 \times 10^{-18}$) with frequency difference measured with 10^{-18} accuracy
- Relativistic geodesy will progress in parallel with the steps towards redefining the second.