

## RECOMMENDED VALUES OF STANDARD FREQUENCIES FOR APPLICATIONS INCLUDING THE PRACTICAL REALIZATION OF THE METRE AND SECONDARY REPRESENTATIONS OF THE DEFINITION OF THE SECOND

### STRONTIUM 87 ATOM ( $f \approx 429$ THz)

$^{87}\text{Sr}$  neutral atom,  $5s^2\ ^1\text{S}_0 - 5s5p\ ^3\text{P}_0$  unperturbed optical transition

#### 1. Recommended value [1] of the frequency in the CIPM List of Frequencies

$$f(^{87}\text{Sr}) = 429\,228\,004\,229\,872.99\ \text{Hz}$$

equivalent to

$$\lambda(^{87}\text{Sr}) = 698\,445\,709.612\,754\,43\ \text{fm},$$

with a relative standard uncertainty of  $1.9 \times 10^{-16}$ .

This radiation was endorsed by the CIPM as a secondary representation of the definition of the second [2].

#### 2. Method to establish the recommended value

A global adjustment of all measurements of frequency ratios published in peer-reviewed publications and available to the CCL-CCTF WGFS was carried out following the methods presented in [3-7].

This adjustment determines the frequency of 14 transitions (see Figure 1) which are either already adopted as secondary representations of the second [7] or considered as candidates for SRS. It took into account 105 measurements, including 33 frequency ratios and 72 absolute frequency measurements (i.e. ratios to the  $^{133}\text{Cs}$  frequency). A total of 483 correlations between these input measurements were estimated and considered in the adjustment. More details on the input data and the processing are provided at [https://webtai.bipm.org/ftp/pub/tai/publication/wgfs/Adjustment\\_2021.html](https://webtai.bipm.org/ftp/pub/tai/publication/wgfs/Adjustment_2021.html). The recommended value is the direct result of the adjustment, rounded as deemed adequate with respect to the recommended uncertainty.

While the results are from a global adjustment, it is of interest to note (see Figure 1) that the  $^{87}\text{Sr}$  transition is involved in 20 measurements relative to  $^{133}\text{Cs}$ , and in 25 frequency ratios, 24 of which are with optical transitions.

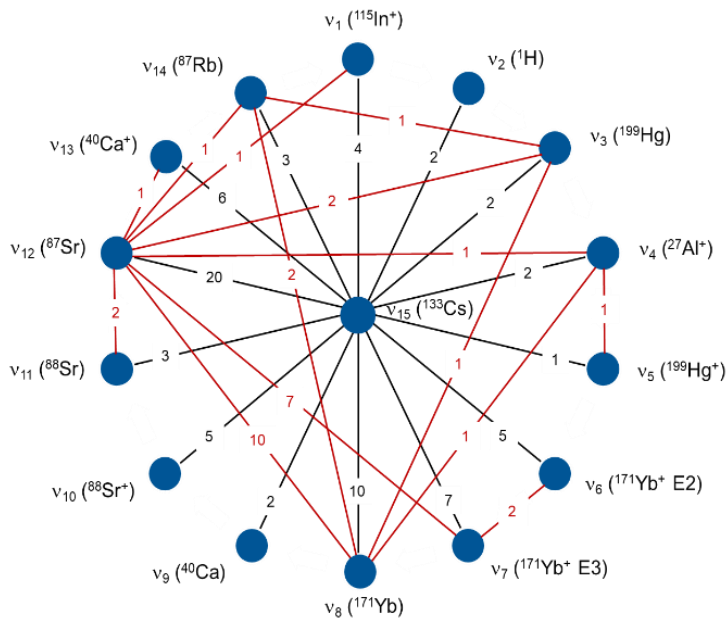


Figure 1: Representation of the 105 measurements linking 14 transitions on the circle and  $^{133}\text{Cs}$  at the center.

### 3. References

- [1] Consultative Committee for Time and Frequency (CCTF), 22<sup>nd</sup> meeting (session II – online), Recommendation PSFS-2 available at <https://www.bipm.org/en/committees/cc/cctf/22-2-2021>
- [2] Recommendation 1 (CI-2006) <https://www.bipm.org/utis/en/pdf/CIPM/CIPM2006-EN.pdf>
- [3] H. S. Margolis, P. Gill: Least-squares analysis of clock frequency comparison data to deduce optimized frequency and frequency ratio values; *Metrologia* **52**, 628 (2015)
- [4] L. Robertsson: On the evaluation of ultra-high-precision frequency ratio measurements: examining closed loops in a graph theory framework; *Metrologia* **53**, 1272 (2016)
- [5] G. Panfilo, communication to the CCL-CCTF WGFS. A new implementation of [4] was realized in MatLab at the BIPM (2020)
- [6] Ch. Oates, communication to the CCL-CCTF WGFS. An independent program was developed in Mathematica at NIST (2017)
- [7] F. Riehle, P. Gill, F. Arias, L. Robertsson: The CIPM List of Recommended Frequency Standard Values: Guidelines and Procedures; *Metrologia* **55**, 188-200 (2018)